

# Gray Bat

*(Myotis grisescens)*

## 5-Year Review: Summary and Evaluation



A cluster of hibernating gray bats in Bellamy Cave, Tennessee. Photo credit: Alvarez Photography

U.S. Fish and Wildlife Service  
Interior Region 3 – Great Lakes

Missouri Ecological Services Field Office  
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with 2024 Addendum



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## **ADDENDUM TO THE GRAY BAT 5-YEAR REVIEW February 2024**

Since the 5-year review draft was completed in October of 2021, additional data were collected that can be used to inform the Endangered Species Act status of the gray bat. State agencies within the range of the gray bat completed hibernaculum surveys in the winter of 2021. Summed together, the Missouri Field Office estimates that there were approximately 4,930,389 gray bats within the 15 major hibernacula in 2021 (Table 1). 5,306,905 bats were estimated during the 2019 winter survey. Given that some of the sites have hundreds of thousands of bats and surveyors must estimate the number of individuals in the colonies, a 7% decline is likely not an indication of population declines and falls within the expected margin of error from such surveys. Thus, the range-wide gray bat population is considered stable. Criterion 2 of the Recovery Plan, which recommends a demonstration of stable or increasing populations at maternity caves for a minimum of 5-years before delisting, continues to be met. For information on how hibernacula data were used to assess Criterion 2, see Section 2.2.2 Documentation of Stable or Increasing Populations at 75% of Priority 1 maternity caves in the 5-Year Review (pg. 16).

Since the review, two more summer use caves were permanently protected through the addition of gates to cave entrances. In total, 33 of 46 (72%) of Category 1 Biologically Significant sites and 21 of 49 (43%) of Category 2 Biologically Significant sites are now permanently protected (Figure 1). Criterion 2 of the Recovery Plan recommends that at least 25% of lower priority maternity colonies are protected in each State before delisting is considered. The goal was nearly met in 2021 when the Review was written, and with the addition of the two gated caves in Missouri since 2021, Criterion 2 has now been met. For information on cave protections and Criterion 3, see Section 2.2.3 Summer Roost Colony Protection Status of the 5-Year Review (pg. 25).

As part of the 5-year review, the Missouri Field Office also assessed wind energy as an emerging threat to gray bats. At the time of the review, there were no active facilities within the gray bat range that could be used to assess the severity of the threat. The analysis predicted potential impacts using two potential build-out scenarios and used the little brown bat to estimate how many gray bats may be killed. Since 2021, the Missouri Field Office has received annual reports from two wind facilities operating under a 10(a)(1)(A) permit to help inform life of the project 10(a)(1)(B) permits. These reports give additional insight into how gray bats may be impacted by wind power generation as new facilities come online in Missouri and other states within the species' range.

The two southwest Missouri wind facilities operate in Barton, Dade, Jasper, and Lawrence counties and are owned by one company. To gain understanding of bat use within the project footprint, pre-construction acoustic and mist net surveys were completed in the summers of 2018 and 2019 within the project areas. At one facility, captured gray bats were outfitted with radio-transmitters and tracked to Wilson's Cave. The cave is approximately 9 miles (15 km) from the eastern facility, Kings Point, and is occupied by a maternity colony with approximately 10,000 bats.

Both facilities are trying to minimize take of gray bats by applying algorithm based smart curtailment technologies. As part of their research, the wind company has been completing intensive post construction mortality monitoring by searching for bat carcasses beneath turbines from Spring 2021 to 2022 active seasons (April 1 – October 31, annually). As of November 2023, one gray bat was found dead at North Fork Ridge and fourteen gray bats have been recovered at Kings Point. However, not all bats are detected during fatality monitoring due to

carcass persistence (e.g., lower persistence is often associated with high densities of scavengers) and searcher efficiency (how often carcasses are detected by surveyors). Using the Service's Evidence of Absence (EoA) software (Dalthorp et al. 2017), which allows estimates of take to be generated knowing that the detection probability is less than 100%, the Missouri Field Office expects that the annual take was likely 11 bats at North Fork Ridge and 77 bats at Kings Point from 2021 to 2022.

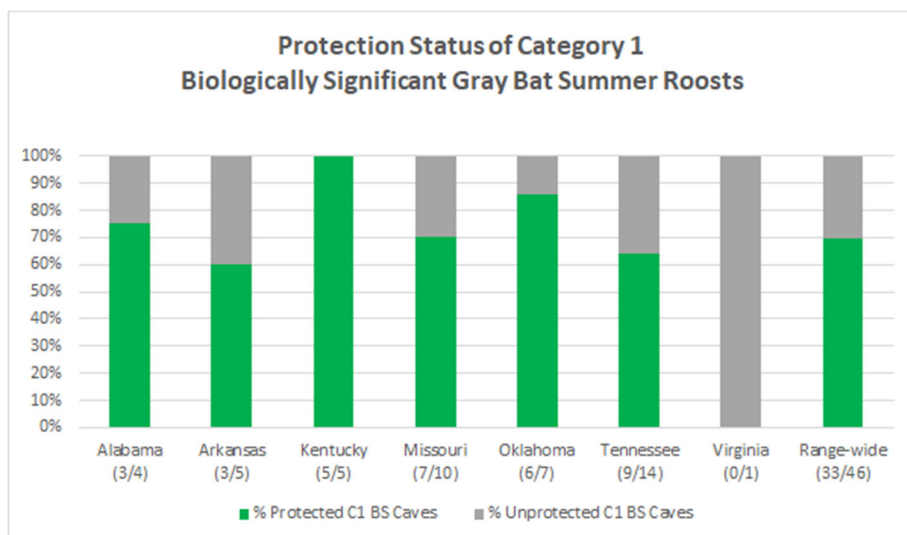
The Missouri Field Office also used the 2022 BatTool ([BatTool application \(usgs.gov\)](https://www.usgs.gov/monitoring-and-evaluation/products-publications/bat-tool-application); Weins et al. 2022) to understand the long-term potential impact of the two wind facilities on the local maternity colony (Wilson Cave) associated with the Kings Point facility. Three different scenarios, ranging from the best-case scenario of no bats killed to the worst-case scenario of bats being killed using permitted take for the projects, were modeled for 50 years with the assumption that the wind facility's life would be 30 years. Our results show that for all three scenarios, there is no chance of extirpation of this maternity colony. In fact, the models estimate positive population growth (lambdas greater than 1) (Table 2). For more information on the analysis, contact Vona Kuczynska with the Missouri Field Office.

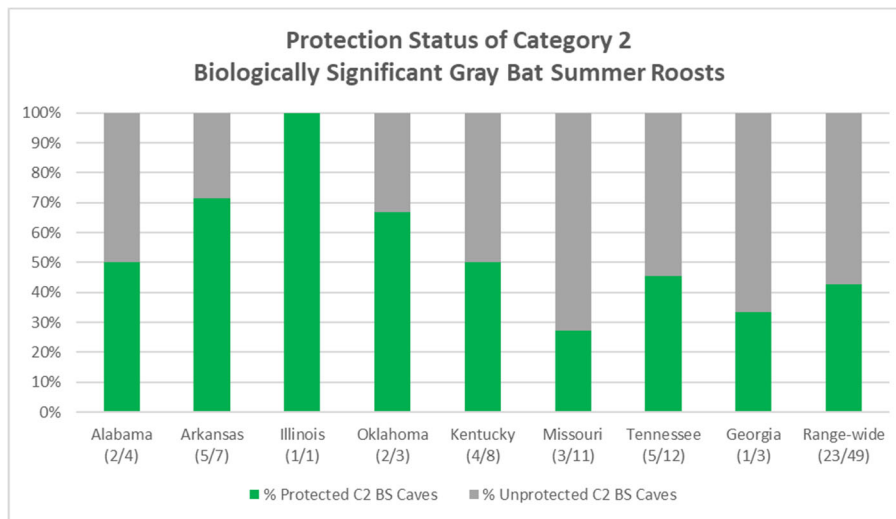
Consequently, we can reasonably conclude that if future wind development is sited near known colonies (maternity or hibernacula) for gray bats, there will be some fatalities. However, the data from southwest Missouri show there are ways to generate energy and minimize impacts to bats through operating turbines using variable cut-in speeds during sensitive time periods (summer and fall migration). Our BatTool model predicts that the maternity colony closest to the two wind facilities will continue to have positive population growth despite some fatalities. As discussed in the 5-year review, there is lower risk of wind energy development in the southeast, particularly near the important strongholds for the species in Tennessee, Kentucky, and Alabama.

**Table 1.** Range-wide population estimates based on survey data from the 15 largest gray bat colony hibernacula, 2010 to 2021.

State	Hibernacula	2010	2011	2012	2013	2014	2015	2016	2017	2019	2021
AL	Fern Cave*								1,289,848	1,349,976	1,349,976
AR	Cave Mountain Cave	390,490	127,670	89,420	138,210	301,920	276,111	606,064	377,060	419,400	341,820
	Blanchard Springs Cavern	97,240	173,740	170,000	172,745	218,815	372,101	372,726	372,445	484,670	304,310
	Bonanza Cave*			190,910		73,780	100,470		82,841	248,000	89,682
FL	Old Indian Cave*	0	3			0	0	0	0	0	0
KY	Coach Cave		80,324		75,596		112,039		76,395	51,769	71,179
	Long Cave		11,920						153,000	313,357	731,629
	Jesse James Cave*		220,104		129,533		214,093		180,406	156,166	102,809
MO	Martin Cave						30,000		42,535	39,051	42,412
	Bat Cave		48,501	11,650	61,172	30,000	20,531		33,500	30,312	17,434
	*Coffin Cave						380,000		577,850	561,936	345,033
	Mose Prater Cave*	110,000					140,200		137,432	137,432	135,000
	Marvel Cave									<200	
TN	Bellamy Cave*	152,159			345,002	310,090	381,475		364,328	414,393	352,134
	Pearson Cave*	208,191			147,265	190,260	431,020		333,430	348,656	383,385
	Hubbards Cave*	513,079			346,286	238,365	283,480		397,116	500,253	441,167
	Tobaccoport Saltpeter Cave*		97	111	52	26	35		379	845	1,234
	Rattling Pit Cave								85,955	250,689	214,175
<b>Range-wide Population Estimate</b>									4,504,520	5,306,905	<b>4,930,389</b>

**Figure 1.** Protection status of Category 1 and 2 Biologically Significant Gray Bat Summer Roosts.





**Table 2.** Summary table showing the resulting population size (N)<sub>t</sub> and expected growth rates (median lambda) for the Wilson Cave gray bat colony for three different Scenarios ran through the BatTool program.

	Median N(t) at year 50	Probability of extirpation in year 50	Median lambda at year 50	Median time to extirpation
Scenario 1	19,456	0	1.001	NA
Scenario 2	19,107	0	1.002	NA
Scenario 3	19,373	0	1.001	NA

## CITATIONS

Dalthorp, Daniel, Huso, Manuela, and Dail, David, 2017, Evidence of absence (v2.0) software user guide: U.S. Geological Survey Data Series 1055, 109 p., <https://doi.org/10.3133/ds1055>.

Wiens, A. M., Schorg, A., Szymanski, J., & Thogmartin, W. E. (2023). BatTool: projecting bat populations facing multiple stressors using a demographic model. *BMC ecology and evolution*, 23(1), 61. <https://doi.org/10.1186/s12862-023-02159-1>

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## **1.0 GENERAL INFORMATION**

### **1.1 Reviewers**

**Lead Field Office:** Missouri ES Field Office, Columbia, MO  
Vona Kuczynska, iwona\_kuczynska@fws.gov

**Lead Region:** Midwest Regional Office (Region 3), Bloomington, MN  
Laura Ragan, laura\_ragan@fws.gov

### **Cooperating Field Offices:**

#### **Region 2**

Oklahoma: Richard Stark, richard\_stark@fws.gov  
Matthew Fullerton, matt\_fullerton@fws.gov

#### **Region 3**

Illinois: Kristen Lundh, kristen\_lundh@fws.gov  
Matt Mangan, matthew\_mangan@fws.gov  
Indiana: Lori Pruitt, lori\_pruitt@fws.gov

#### **Region 4**

Alabama: Shannon Holbrook, shannon\_holbrook@fws.gov  
Arkansas: Thomas Inebnit, thomas\_inebnit@fws.gov  
Florida: Lourdes Mena, lourdes\_Mena@fws.gov  
Georgia: Laci Pattavina, laci\_pattavina@fws.gov  
Kentucky: Mike Armstrong, mike\_armstrong@fws.gov  
Mississippi: Kelly Morris, kelly\_morris@fws.gov  
North Carolina: Susan Cameron, susan\_cameron@fws.gov  
Tennessee: David Pelren, david\_pelren@fws.gov

#### **Region 5**

West Virginia: Jennifer Norris jennifer\_1\_norris@fws.gov  
Virginia: Sumalee Hoskin, sumalee\_hoskin@fws.gov

#### **Region 6**

Kansas: Michele McNulty, michele\_mcnulty@fws.gov

### **Cooperating Regional Offices:**

R2: Angela Anders, angela\_anders@fws.gov  
R4: Carrie Straight, carrie\_straight@fws.gov  
R5: Martin Miller, martin\_miller@fws.gov  
R6: Craig Hansen, craig\_hansen@fws.gov

## **1.2 Methods used to complete the review:**

This 5-Year Review (review) was prepared by Vona Kuczynska, Endangered Species Biologist, U.S. Fish and Wildlife Service (Service), Missouri Ecological Services Field Office (Missouri Field Office) in consultation with Service and state biologists from throughout the species' range. The review was written with assistance from Trisha Crabill, Laurel Hill and Ashley Riedel with the Missouri Field Office. Shelly Colatskie, Mike Armstrong and David Pelren provided much of the background information as well as feedback through all stages of the review. Dr. Lisa Webb with the USGS Missouri Cooperative Fish and Wildlife Unit, Dr. Florian Weller and Dr. Rachel Blakey with the University of Missouri (Columbia, Missouri) helped to organize survey data and complete the population trend analysis. Giorgia Auteri with the University of Michigan and Dr. Sybil Amelon with the Forest Service provided input on the genetics and white-nose syndrome section of the review.

To prepare this status review, the Service solicited pertinent information from the public through Federal Register notice 84 FR 17420 on April 25, 2019 and reviewed scientific publications, as well as published and unpublished records that became available since the previous 5-year review in 2009. Special attention was given to new information received since the 2009 review to update status trends and threats.

The Service announced the initiation of the review on April 25, 2019 in the Federal Register. No public comments related to new substantive information about the species' status or threats were received. Since publication of the 2009 review, however, the Service has coordinated with State and Federal natural resource agencies and partners in 14 states and has received new population data collected as part of biennial gray bat winter population surveys, summer roost surveys, and summaries of the current protection status of gray bat sites. These data were used in conjunction with the most recent population and threats data from across the species' range to assess the current status of the species

## **1.3 Background**

The gray bat is a species that occurs across a limited geographic range in limestone karst areas of the southeastern United States. Hibernating populations are concentrated in caves across northern Alabama and Arkansas, Kentucky, Missouri, and Tennessee. The summer range extends eastward from eastern Oklahoma and very southeastern Kansas<sup>1</sup>, across southern Illinois and Indiana and out to southwestern Virginia, western North Carolina, and northwest section of Georgia. Historically, some small populations used to, but no longer, roost in northwestern Florida and there have been rare cases of foraging gray bats

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<sup>1</sup> There is only one confirmed maternity colony in Cherokee and another in Crawford County, KS.

observed in the very northeastern county in Mississippi<sup>1</sup> (Sherman and Martin 2006). With only two winter hibernacula records and a single summer record (an adult male), the gray bat is considered an incidental species in West Virginia<sup>2</sup>. The approximate range of the gray bat, based on subterranean roost locations (i.e., caves and human-made structures such as mines, quarries, storm sewers, culverts, but also above-ground bridges and dams), mist net captures, other visually confirmed records, and assumed flight pathways between roosts is provided as Figure 1.



**Figure 1.** The approximate range of the gray bat, based on subterranean and above-ground roost locations and mist net captures, visually confirmed records, and assumed flight pathways between roosts. Many acoustic recordings classified as gray bat fall outside the estimated range provided here, especially in southern Illinois and southern Indiana, but the presence of gray bats in these areas has not been verified with physical captures.

<sup>1</sup> The gray bat does not appear to breed or hibernate in Mississippi. Gray bats have been historically documented in very low numbers in Mississippi and in just a few instances. White (1961) documented several gray bats in 1961 from a chalk mine in Tishomingo County (in the extreme northeastern corner of the state). In 2004, a single dead male gray bat was recorded in Tishomingo County. Gray bats in Mississippi may be foraging individuals from Blowing Springs Cave in Alabama, and documented individuals do not necessarily represent the existence of a local breeding population (Sherman and Martin 2006).

<sup>2</sup>Alexander Silvis, endangered species biologist with the West Virginia Division of Natural Resources, February 16, 2021

The main historical threats to the gray bat have been human disturbance to roosting bats, environmental contamination, impoundment of waterways, roost modification or destruction (i.e., cave entrance or mine sealing, modification of the internal environment and entrances), cave commercialization, improper gating, and natural calamities such as cave-ins and flood events. Emerging threats, such as interactions with wind turbines, climate change, and white-nose syndrome (WNS) have been added as potential threats since gray bats were first federally listed in 1976. A more detailed description of historical threats is provided in the Recovery Plan and 2009 5-Year Review (USFWS 1982; USFWS 2009, respectively).

**FR Notice Citations announcing initiation of this review:**

84 FR 17420 (April 25, 2019) Endangered and Threatened Wildlife and Plants; Initiation of 5-Year Status Reviews of Six Listed Animal and Plant Species.

#### **1.4 Listing History**

Original Listing

**FR notice:** 41 FR 17736 17740

**Date Listed and Critical Habitat Designated:** 4/28/1976

**Entity Listed:** Gray bat – *Myotis grisescens* (the species)

**Classification:** Endangered

**Associated rulemakings:** No associated rulemakings have been published.

#### **1.5 Review History**

The gray bat was included in 5-Year Reviews on February 27, 1981, July 7, 1987, November 6, 1991, and September 30, 2009.

After the gray bat was listed, a Recovery Plan was finalized in 1982 by an interagency recovery team of experts (USFWS 1982). The plan describes four criteria to consider when reviewing the status and considering gray bat reclassification (Table 1). The criteria relate to protecting caves that are used by the largest overwintering and summer gray bat colonies and monitoring these populations for at least a five-year period to evaluate if management actions taken to protect them were successful. The Recovery Plan outlines conservation actions such as the protection of caves through conservation easements, land acquisition, or installation of properly designed, physical barriers (gates, fences) that protect bats from disturbance.

**TABLE 1.** The four recovery criteria outlined in the 1982 Recovery Plan that the interagency recovery team recommended are considered when making down-listing and de-listing decisions for the gray bat (USFWS 1982).

Reclassification Pathway		Relevant Measure
Endangered to Threatened	Criterion 1	Permanent protection <sup>1</sup> of 90% of Priority 1 hibernacula.
	Criterion 2	Stable or increasing populations at 75% of Priority 1 maternity caves over a period of 5 years.
Threatened to Recovered	Criterion 3	Permanent protection <sup>1</sup> of 25% of Priority 2 caves in each state.
	Criterion 4	Stable or increasing populations at 25% of Priority 2 caves in each state.

<sup>1</sup>According to the Recovery Plan, to be considered permanently protected, caves can be publicly or privately owned, but there must be a long-term voluntary landowner agreement, such as a stewardship plan, conservation easement, habitat management plan, or memorandum of agreement that protects caves in perpetuity. Protection of caves includes ensuring minimal disturbance of bats during the hibernating and reproductive season.

The Recovery Plan team members assigned priority actions to caves and put the actions into priority tiers based on the perceived importance for recovering the species. Actions outlined for Priority 1 caves were considered essential to prevent the extinction of the species. Priority 1 caves include major hibernacula (roosts where bats overwinter) and largest or ‘primary’ summer maternity colonies. Actions outlined for Priority 2 caves were considered necessary to maintain the species’ current population status. Priority 2 caves include smaller sized or ‘secondary’ maternity and bachelor colonies as well as the less populated hibernation sites.

Since the gray bat was listed in 1976, regional and range-wide assessments have intermittently estimated gray bat population sizes and recovery progress. In the late 1970s, the total population of gray bats was estimated at approximately 1,575,000 (Tuttle 1979) and thought to be approximately 1,657,900 by the time the Recovery Plan was written in 1982 (Ellison et al. 2003). By 2000, Harvey (2001) estimated there to be approximately 2.3 million bats. Ellison et al. (2003) conducted a range-wide assessment of trends of gray bat summer roost populations and found few detectable trends from both maternity and hibernacula population data, likely as a result of highly variable data. Sasse et al. (2007) analyzed the status of 48 maternity colonies in the western portion of the gray bat’s range from 1978 to 2002 and concluded that 79% of the colonies were stable or increasing. Harvey and Currie completed a status review in 2007 and estimated the 2006 population to be 3,377,100 – an increase of 104% from the 1982 estimate of 1,657,900 (Harvey and Currie 2007).

Another range-wide comprehensive review was completed in 2007 by the U.S. Army Corps of Engineers (Martin 2007). The author concluded that gray bat populations

increased from 2005 to 2007 across most primary summer and winter caves. Elliott (2007) examined population trends of gray bats at nine, Priority 1 caves and concluded that although the species had increased by approximately 21% between 1980 and 2005, it had only reached roughly 37% of its maximum historical populations at these sites.

The 2009 5-Year Review concluded that gray bats had recovered in many areas and that the overall range-wide estimate was increasing. Despite the achievements in recovery, the potential threat of white-nose syndrome was considered of such magnitude that no change in status was recommended (USFWS 2009). The most current (2019) population estimate indicates there are approximately 5.3 to 5.4 million gray bats range-wide (USFWS, unpublished data, February 2021).

**Species' Recovery Priority Number at start of 5-year review: 8**

The recovery priority number for the gray bat is 8; indicative of a species with a moderate degree of threat and high recovery potential.

**Recovery Plan or Outline**

**Name of Plan:** Gray Bat Recovery Plan

**Date Issued:** July 8, 1982

## **2.0 REVIEW ANALYSIS**

### **2.1 Application of the 1996 Distinct Population Segment (DPS) Policy:**

Is the species under review a vertebrate? Yes.

Is the species under review listed as a DPS? No.

Was the DPS listed prior to 1996? Not Applicable.

Is there relevant new information for this species regarding the application of the DPS policy? No.

### **2.2 Recovery Criteria:**

#### **Does the species have an approved recovery plan containing objective, measurable criteria?**

In part, yes. In the Recovery Plan, gray bat caves, mines, quarries, culverts and other human-made structures (hereafter collectively called gray bat “roosts” or ‘gray bat sites” for simplicity) were assigned Priority conservation actions. Criteria 1 and 3, which require documentation of permanent protection of 90% of Priority 1 hibernacula (roosts where bats overwinter) and 25% of Priority 2 summer use roosts are measurable. Criteria 2 and 4, which include documentation of stable or increasing populations at 75% of Priority 1 maternity sites over a period of five years and at 25% of Priority 2 roosts in each State have proven difficult to measure. While States complete maternity roost censuses when possible, many have mostly shifted focus to systematic winter surveys of the most populous hibernacula as the primary tool for assessing recovery of populations. There is no criterion in the Recovery Plan that addresses documenting stable or increasing populations in hibernacula.

#### **Adequacy of recovery criteria:**

#### **Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?**

No. Attenuation of threats and protection measures at some roosts improved habitat and shifted the biological significance of numerous sites, which confound the original priority designations outlined in the Recovery Plan. Numerous Priority 1 and Priority 2 summer sites in the Recovery Plan are no longer occupied by gray bats (e.g., Priority 1 Chrismans Cave in Kentucky), and some roosts discovered or surveyed since 1982 are now considered to be more significant than the Priority roosts outlined in the plan. State agencies are not tracking the number of sites that are no longer occupied. There is also at least one site that was designated as a Priority cave that was likely mistaken for another cave, which was never occupied by gray bats (Priority 2 Portersville Cave, Alabama). Rather than review the status of completion for Priority 1 and 2 action assignments,

which in many cases are now outdated, future reviews could rely on updated methods for assessing recovery that are introduced and used in this review.

The Recovery Plan assigned Biological Significance ranks (primary, secondary, other) for gray bat roost sites based on the size of the colony using the roost. Biological Significance ranks provide a straightforward way to classify sites in terms of their importance based on population estimates. As part of this review, gray bat roosts were assigned into three Biologically Significance categories (e.g., Category 1, 2, and 3) that can be updated as population data is collected and used in future species assessments. See Section 2.1.3 for Category definitions.

**Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and is there no new information to consider regarding existing or new threats)?**

No. Although protection of hibernacula can help address some of the threats, there are no explicit criteria that address other threats. Specifically, threats faced during migration, spring, fall, and summer are not explicitly addressed, although the criteria that call for stable or increasing numbers would reflect the extent to which threats have been influencing populations throughout their life cycle.

**Current recovery criteria and achievements:**

**List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information.**

Table 1 contains a summary of the recovery criteria. A detailed assessment of each of the four criteria has been completed as part of this review. Three of the four recovery criteria have been achieved outright or by using alternative methods and the 4<sup>th</sup> criterion has been nearly met.

As previously stated, in the Recovery Plan, caves but also mines, quarries, culverts and other artificial subterranean structures created by humans that are cave-like and regularly used by gray bats (hereafter collectively called “gray bat roosts” or ‘gray bat sites”) were assigned Priority conservation actions deemed necessary to recover the species. Conservation actions were ranked in terms of their priority (a scale of 1 to 4, with 1 having the highest priority and 4 requiring no action). Priority levels were loosely set based on biological significance (size) of the colony, the roost location, vulnerability, and consensus of opinion of the Recovery Team members. Actions outlined for Priority 1 caves were considered absolutely essential to prevent the extinction of the species. Priority 1 caves include major hibernacula and largest or ‘primary’ summer maternity colonies. Actions outlined for Priority 2 caves were considered necessary to maintain the species’ current population status. Priority 2 caves include smaller sized or ‘secondary’ maternity and bachelor colonies as well as the less populated hibernation sites. Priority 3 caves had no assigned actions and included are those that require further investigation. Priority 4 caves are all remaining known caves, most of which are of marginal consequence and require no action. The list of Priority 1 and 2 gray bat sites is provided as Table 2.

The Recovery Plan includes specific conservation actions to Priority 1 and 2 caves, including, but not limited to, gating, fencing, signage, land acquisition, prevent flooding, maintenance, and no action. No actions were assigned to Priority 3 and 4 caves other than stating that some sites need more investigation. In this review, we assess the progress made to gray bat roosts with regard to Priority 1 and 2 assignments, but given the outdated nature of the assignments, we also update Biological Significance assignments for both summer and winter sites based on current information.

In total, the Recovery Plan outlines 42 Priority 1 caves. Of these, 10 are Priority 1 hibernacula and 32 contain Priority 1 maternity colonies (Table 2). The Recovery Plan states that the designated 129 Priority 2 caves “are those containing fewer bats” and does not indicate if at the time of listing, any of these caves were limited to summer use from maternity and bachelor colonies, or if they also included any known, smaller hibernacula. Because the Recovery Plan does not categorize Priority 2 caves by their use, but some of these caves are now major hibernacula for gray bats (e.g., Blanchard Springs Cavern in AR, Long Cave and Coach Cave in KY), we assume that some bats may have inhabited these caves in the winter at the time the plan was written. Thus, we consider the Recovery Plan to have meant that Priority 2 caves include both summer and hibernacula caves with fewer bats than Priority 1 caves.

**TABLE 2.** A list of Priority 1 and 2 caves provided in the Recovery Plan. Priority 1 caves were designated as major hibernacula and their most important maternity colonies. Some of the caves are now occupied by bachelor (B) and mixed-use (adult male and female) colonies. Priority 2 caves were designated as those containing fewer bats that are important for geographic or other reasons. The Priority 2 list includes both maternity and bachelor colonies. Bold indicates the Priority 1 hibernacula.

State	Priority 1 Caves (maternity colonies and their hibernacula)	Priority 2 Caves (maternity and bachelor colonies)	Priority 2 Caves, continued
Alabama	Georgetown	Baker Cave	
	Cave Spring Cave	Blowing Springs Cave	
	<b>Fern Cave (Hibernaculum)</b>	Gross Skeleton Cave	
	Hambrick Cave	Anderson Cave	
	Key Cave	Guntersville Caverns	
	Sanders Cave	Indian Cave	
	Sauta Cave (B)	Old Blowing Cave	
Arkansas	<b>Bonanza Cave (Hibernaculum)</b>	Bald Scrapy Cave	Horsethief Cave
	Bone Cave	Bennett Cave	Joe Bright Cave
	Logan Cave	Blanchard Springs Cavern (B)	John Eddings Cave
		Blagg Cave	Little Bear Cave
		Brewer Cave	Old Joe Cave
		Cave Mountain Cave (Hibernaculum)	Optimus Cave
		Cave River Cave	Ozark Acres Cave
		Cave Springs Cave	Peter Cave
		Crane Cave	Pigeon Roost Cave
		Crystal Cave	Rory Cave
		Diamond Cave	Rowland Cave
		Fallout Cave	War Eagle Creek Cave
		Hankins Cave	Sneads Bat Cave
	Hell Creek Cave		
Florida	Geromes Cave		
	Girards/Miltons Cave		
	Judges Cave		
	<b>Old Indian Cave (Hibernaculum)</b>		
Illinois	Cave Springs Cave		
Kansas		Storm Sewer/Pittsburg	
Kentucky	Chrismans Cave	Big Sulphur Springs Cave/Pee Dee (B)	Daniel Boone Cave
	Cool Springs Cave	Blowing Cave	Jones Cave
	Holland/Carpenter Cave	Burgess Cave	Long Cave (Hibernaculum)
	<b>Jesse James Cave (Hibernaculum)</b>	Caney Branch Cave	Payne/Temple Hill Saltpeter Cave
	Overstreet Cave	Coach Cave (Hibernaculum)	Riders Mill Cave
Missouri	Bat Cave (Dent County)	Adkins Cave	Holton Cave
	Saltpeter Cave (Stone County)	Blackwell Cave	Hunter's Cave
	Beck Cave	Bat Cave #1 (Miller County)	Indian Ford Cave
	<b>Coffin Cave (Hibernaculum)</b>	Bat Cave #1 (Pulaski County)	Lewis and Clark Cave
	Great Spirit/Inca Cave	Bat Cave #2 (Franklin County)	Lower Burnt Mill Cave
	<b>Marvel Cave (Hibernaculum)</b>	Bat Cave #2 (Pulaski County)	Martin Cave
	Roaring Springs Cave	Bat Cave (Ozark County)	Mary Lawson Cave
	<b>Mose Prater/Chimney Cave (Hibernaculum)</b>	Bat Cave (Oregon County)	Mayfield Cave
	Moles Cave	Bat Cave (Laclede County)	Maze Cave
	Toby/Mauss Cave	Big Mouth Cave	McDowell Cave
	Tumbling Creek Cave	Carroll Cave	McKee Cave
		Cat Hollow Cave	Onyx Cave
		Coalbank Cave	Piquet Cave
		Cooks Cave	Prairie Hollow Cave
		Coolbrook Cave	Rantz Cave
		Devil's Icebox Cave (MU)	River Cave Ha Ha Tonka (Camden)
		Dry Branch Cave	Rocheport (Boone) Cave
		Estes Cave	Round Spring Cavern
		Fiery Forks Cave	Saloon Cave
		Fisher Cave (Franklin County)	Shamel Cave
		Fisher Cave (Ralls County)	Smittle Cave
		Frankford Cave	Tunnel Cave
		Freeman Cave	Twenty-three Degree Cave
	Grandpa Chippley's Cave	Twin Springs Cave	
	Great Scott Cave	Unnamed Cave (Cole County)	
	Hannah Cave	Windy Cave	
	Hilderbrand Cave		
Oklahoma	Stansberry Cave (B)	Charley Owl Cave	
		Linda Bear Paw Cave	
		Spavinaw Bat Cave	
Tennessee	Bellamy Cave (Hibernaculum)	Alexander Cave	Herring Cave
	Cripps Mill Cave	Arment Cave	Horner Cave
	<b>Hubbards Cave (Hibernaculum)</b>	Baloney Cave	Lost Creek Cave
	Indian Cave	Featherfoot Cave	Markham Cave
	Nickajack Cave	Eves Cave	Norris Dam Cave
	Oaks Cave	Bat Cave (Hickman County)	Piper Cave
	<b>Pearson Cave (Hibernaculum)</b>	Bat Cave (Lincoln County)	Sensabaugh Cave
	<b>Tobaccoport Saltpeter Cave (Hibernaculum)</b>	Benderman Cave	Shipman Creek Cave
	White Buis Cave	Blythe Ferry Cave	Trussell Cave
		Bridgewater Cave	Woods Dam
		Caney Hollow Cave	
		Gin Bluff Cave	
		Grassy Creek Cave	
		Dud's Cave	
	Harris Cave		
Virginia		Clinchporrt Cave	

### **2.2.1 Criterion 1: Documentation of permanent protection of 90% of Priority 1 hibernacula.**

The ten Priority 1 hibernacula listed in the 1982 Recovery Plan were chosen for their biological significance, location, vulnerability and consensus of opinion that these caves require protection and management for the gray bat to achieve recovery. To be considered permanently protected, hibernacula can be publicly or privately owned, but there must be a long-term voluntary landowner agreement, such as a stewardship plan, conservation easement, habitat management plan, or memorandum of agreement that protects hibernacula in perpetuity. Protection of hibernacula includes ensuring minimal disturbance of bats during the hibernation season (e.g., only authorized surveys or other conservation-related activities).

Three of the Priority 1 hibernacula listed in the Recovery Plan are no longer considered to be important gray bat sites. Although Old Indian Cave in Florida was listed as a Priority 1 cave in the Recovery Plan and protection for this cave has been secured, this and all other gray bat caves in Florida are considered to be abandoned since 2011. Human disturbance to these caves has not been documented and is not considered the reason for abandonment. It is likely that bats from Florida moved to Alabama, because this significantly reduces the travel distance between the hibernacula and summer sites (Gore et al. 2012). Another cave that was listed as a Priority 1 is Marvel Cave in Missouri, which is now a privately-owned show cave that currently contains a very small number of hibernating bats. Only 134 gray bats were counted during the 2020 winter survey (Shelly Colatskie, pers. comm., 2021<sup>1</sup>). Tobbaccoport Saltpeter Cave in Tennessee has been surveyed by the Service and The Nature Conservancy (TNC) 8 times since 2000, and the number of bats in this hibernaculum has ranged between 4,621 and 16,500. The dome room of the cave is unlikely to have ever supported the large number of bats once assumed and is unlikely to do so in the future (Holliday, pers. comm., 2020<sup>2</sup>). Of these three caves, only Marvel Cave is not considered protected. All other Priority 1 hibernacula are considered protected, resulting in 90% protection (even though some are no longer considered significant hibernation sites).

Although the Recovery Plan outlined 10 Priority 1 hibernacula, 7 caves should be added to the list of major, or most populous, gray bat hibernacula, and their protection status is assessed as part of this review. Several of these caves now support some of the largest hibernating gray bat populations, and in many cases their populations have surpassed those of the 10 Priority 1 hibernacula. Six of the 7 caves are permanently protected due to their importance as hibernation sites, with the 7<sup>th</sup> being only partially protected (Martin Cave, MO). The population numbers for the 7 sites in the list below are based on surveys conducted during winter of 2019.

1. Rattling Pit Cave (TN) is inhabited by approximately 250,000 bats and is the 4<sup>th</sup> largest gray bat hibernaculum in Tennessee (the top 3 are already Priority 1 caves).
2. Blanchard Springs Caverns (AR) is inhabited by 484,670 bats and has nearly double the number of bats present at a Priority 1 cave in the state.

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<sup>1</sup> Shelly Colatskie, biologist with Missouri Department of Conservation, January 5, 2021

<sup>2</sup> Cory Holliday, biologist with The Nature Conservancy, August 8, 2020

3. Cave Mountain Cave (AR) has 419,400 bats and is the second largest hibernaculum in the state.
4. Coach Cave (KY) is inhabited by 51,769 bats.
5. Long Cave (KY) has 313,357 bats, more than double the number of bats present at the Priority 1 cave for the state.
6. Bat Cave (Shannon County, MO) has 30,312 bats and is the 4<sup>th</sup> largest hibernaculum.
7. Martin Cave has 39,051 bats and is the 3<sup>rd</sup> largest gray bat hibernaculum in Missouri.

For a complete list of current and past major hibernacula, see Table 3. Smaller hibernacula with few hibernating bats (e.g., Wyandotte Cave, Indiana: 1,380 bats recorded overwintering in 2019; Anticline Cave, Oklahoma: 9,800 recorded overwintering in 2018; Great Scott Cave, Missouri: 700 to 4,000 depending on year) were excluded from this list because they are not considered major sites. Additionally, Figure 2 provides the general locations of currently occupied, major hibernacula for gray bats. State and Federal partners are actively working to monitor and prevent disturbance to these caves.

Conservation measures undertaken at Priority 1 hibernacula are excellent examples of partnerships developed between the USFWS and other Federal, State, and private entities that have contributed to the recovery of gray bats. A significant 2019 accomplishment involved The Nature Conservancy's (TNC) purchase and permanent protection of Coach Cave and Jesse James Cave - 2 major gray bat hibernacula discussed above. Together, these caves support a large percentage of gray bats hibernating in Kentucky. Securing these sites was the result of a collaboration between the Service's Kentucky Field Office, Kentucky Department of Fish and Wildlife Resources, TNC in Kentucky, and Kentucky Natural Lands Trust, and James Cave Project, Inc. (Armstrong, pers. comm., 2020<sup>1</sup>). Bat Cave Shannon County was also protected with a bat friendly, flyover, angle iron gate in cooperation with Missouri Department of Conservation, The Nature Conservancy, U.S Fish and Wildlife Service, Missouri Department of Natural Resources - State Parks, Ozark Scenic Riverways (National Park Service), and Karst Solutions.

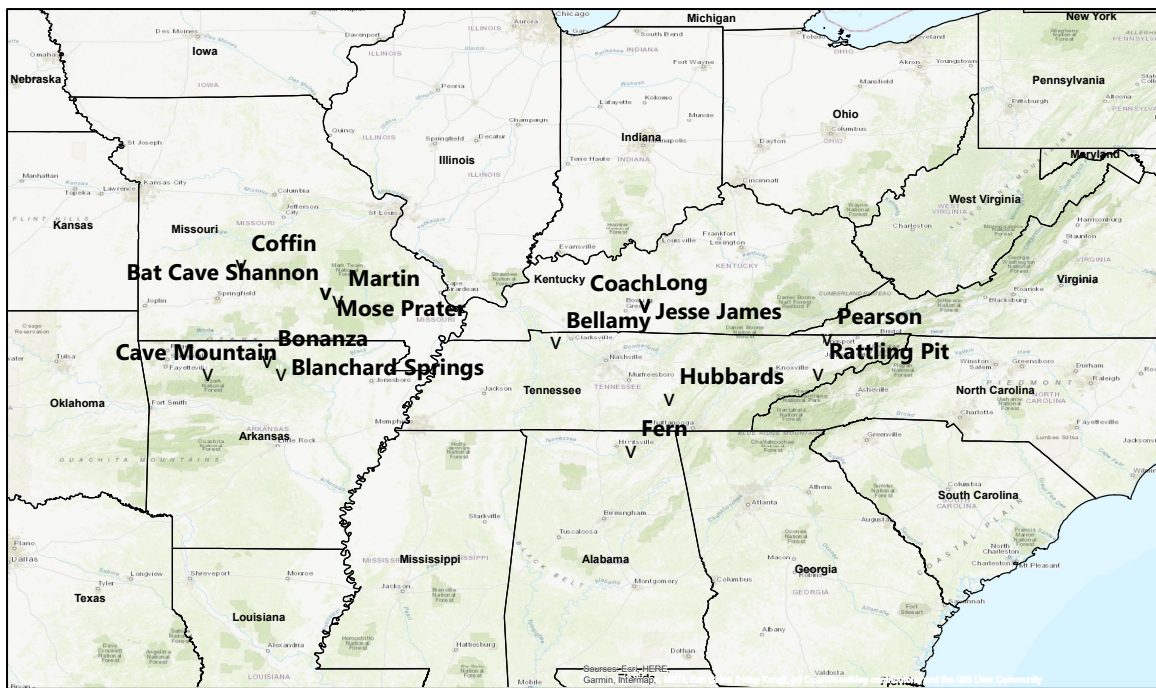
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<sup>1</sup> Mike Armstrong, biologist with the Kentucky Ecological Services, U.S. Fish and Wildlife Service Field Office. August 4, 2020

**TABLE 3.** Protection status of major gray bat hibernacula. The seven major hibernacula that have been added (not included in the Recovery Plan as a Priority 1 cave) are marked with an asterisk.

State	Cave Name	How Is Disturbance Controlled?	Owner	Owner Type	Has Protection Been Secured?
AL	Fern Cave	Difficult to Access	U.S Fish and Wildlife Service	Federal	YES
AR	Blanchard Springs Caverns*	Fenced	U.S Forest Service	Federal	YES
	Bonanza Cave	Gated	U.S Forest Service	Federal	YES
	Cave Mountain Cave*	Fenced	National Park Service	Federal	YES
FL	Old Indian Cave (Abandoned)	Fenced	Florida Department of Environmental Protection	State	YES
KY	Coach Cave*	Gated	The Nature Conservancy	Private	YES
	Jesse James Cave	Gated	The Nature Conservancy	Private	YES
	Long Cave*	Gated	National Park Service	Federal	YES
MO	Bat Cave (Shannon Co)*	Gated	Missouri Department of Conservation	State	YES
	Coffin Cave	Chain link fence and Difficult to Access	Missouri Department of Conservation	State	YES
	Mose Prater Cave	Angle iron gate and Difficult to Access	National Park Service	Federal	YES
	Martin Cave*	Entrance 1 Gated, Entrance 2 Not Protected	Private	Private	YES and NO
	Marvel Cave (Very low use)	Not Protected	Private	Private	NO
TN	Bellamy Cave	Fenced	Tennessee Wildlife Resources Agency	State	YES
	Hubbards Cave	Gated	The Nature Conservancy	Private	YES
	Pearson Cave	Gated	Tennessee Wildlife Resources Agency	State	YES
	Rattling Pit Cave*	Difficult to Access	City of Newport, TN	City	YES
	Tobaccoport Saltpeter Cave <sup>1</sup> (Very low use)	Fenced	Private individual	Private	YES

<sup>1</sup> While Tobaccoport Saltpeter Cave (TN) currently has low winter use, the site supports a summer gray bat maternity site with approximately 15,000 adult bats.



**FIGURE 2.** The general locations of the 15 most populous (major) gray bat hibernacula (“H”). Due to their current low populations (<1,000 bats), Priority 1 Old Indian Cave (FL), Tobaccoport Saltpeter Cave (TN), and Marvel Cave (MO) are not included.

**Status of Reclassification Criterion 1: ACHIEVED.**

This criterion directly addresses threats to major hibernacula and ensures that these are also addressed throughout the range (i.e., ensure population redundancy). Of the Priority 1 hibernacula caves listed in the 1982 Recovery Plan, 90% have been permanently protected, although 3 of the caves that historically had significant populations (Marvel Cave, Tobaccoport Saltpeter Cave, and Old Indian Cave) now support few to no bats. The updated list contains 15 major hibernacula, and 14 of these are considered permanently protected (93%) (Table 3). Thus, by achieving this criterion, a significant proportion of the gray bat range-wide population will be protected from disturbance in its winter habitat. Protection of hibernacula is a primary focus of the Recovery Plan for this species (USFWS 1982).

**2.2.2 Criterion 2: Documentation of stable or increasing populations at 75% of Priority 1 maternity caves**

The Recovery Team used the best available information to designate caves as Priority 1 maternity caves. The Recovery Team identified caves that should be used in the basis for reclassification and delisting of the gray bat (Table 2). However, since 1982, some of these caves have become abandoned or have such low populations of gray bats that they are no longer considered to be significant sites; while other maternity caves have been identified as deserving prioritization for protection and monitoring<sup>1</sup>. The abandonment, irregular use or low bat presence at some of these previously large roosts may be due to

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<sup>1</sup> For an updated list and definition of Biologically Significant gray bat sites in each state, see Appendix A. 20

human or environmental disturbance (e.g., flooding), but in many instances, the cause has not been established. For example, in Kentucky, Chrismans Cave (Priority 1) is no longer occupied by gray bats, but Caney Branch, Burgess, Boone's, and Jones caves are all non-Priority caves that are now considered important summer sites based on their location and estimated summer populations (Armstrong, pers. comm., 2020<sup>1</sup>). As a result, less effort has been put forth to protect and monitor abandoned or less populated Priority 1 sites, but a great deal of effort has been placed on monitoring and protecting some Biologically Significant sites that were not covered Priority 1 or 2 sites.

To meet Criterion 2, stable or increasing populations need to be documented at 75% of Priority 1 maternity caves. This criterion cannot be assessed as recommended in the Recovery Plan because too few Priority maternity caves outlined in the Recovery Plan have been monitored annually, or for a consecutive 5-year period. However, there are valid reasons for the lack of surveys at many Priority 1 maternity caves, including: sites are no longer significant because they have few to no bats; State agencies lack funding and time to complete surveys, especially in states that have 4 or more Priority 1 caves; caves occur on private property where access cannot be obtained annually or on a regular basis; and lack of access to costly equipment needed to conduct surveys using infrared or thermal recordings (to avoid disturbance to maternity colonies). It is also worthwhile to highlight the ambitious nature of this criterion, which recommended that nearly 75% of 32 Priority 1 sites (and in Criterion 4 at least 25% of 129 Priority 2 sites) be monitored over a 5-year period. Surveys require substantial time and effort by each State and are not always feasible.

Another concern with documenting stable or increasing populations at maternity sites is that there is not a widely accurate means of estimating maternity colony population size. For example, bats may emerge from a cave that has a very wide mouth, and the thermal infra-red or near-infrared camera field of view can only capture 70% of emerging bats (e.g., Rocheport Cave, MO). In other situations, the bats emerge over water (e.g., Buffalo Quarry, MO) and cameras cannot be held steadily in a boat to record emerging bats. Other methods, like population estimates from the guano surface area, cannot be completed at some of the locations because bats roost over water and defecate directly into water. Therefore, there is wide variation in the assumed accuracy of maternity colony size population estimates from site to site.

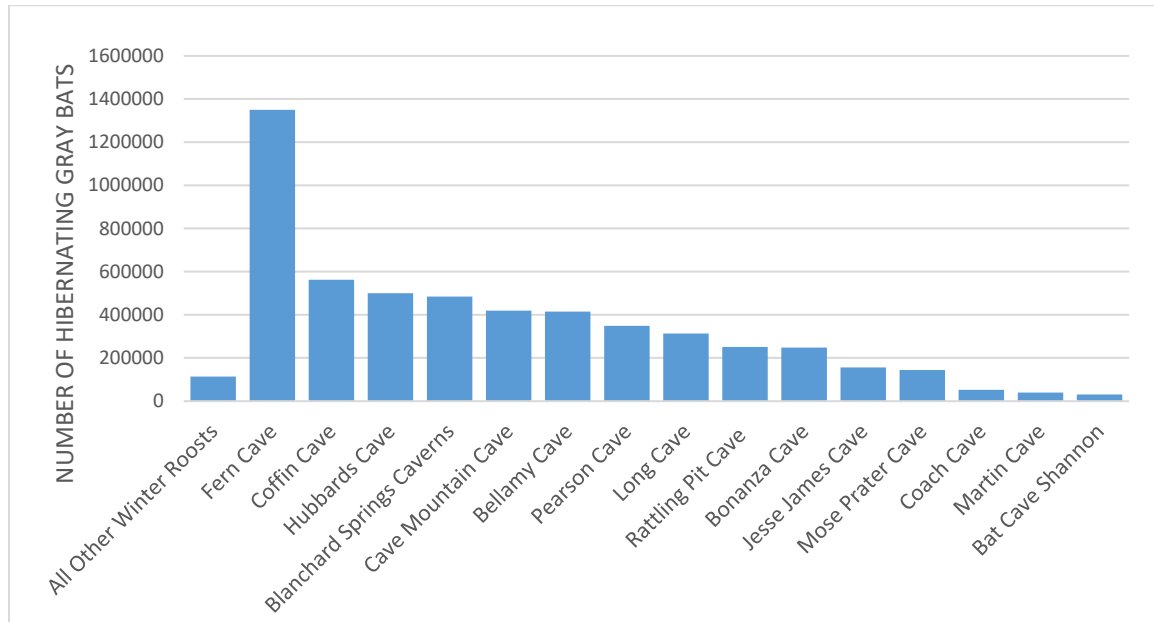
Because there are not enough data to assess if Criterion 2 has been met using the recommended measure, the stability and population trend of maternity colonies was assessed using an alternate method. Bats in hibernacula represent individuals that have survived and successfully reproduced during the summer season. Approximately 98% of known gray bats are estimated to hibernate in 15 major hibernacula most of which are protected by the federal/state/non-governmental ownership (Figure 3). Other small overwintering populations are known to occur, but the numbers in these sites are small compared to the major sites. For example, Fricks, Sitton's, and Chickamauga Cave in Georgia each have fewer than 50 individuals hibernating during the winter (Pattavina, pers. comm., 2021<sup>2</sup>). The largest known non-major hibernacula include Boy Scout in

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<sup>1</sup> Mike Armstrong, biologist with the U.S. Fish and Wildlife Service, October 1, 2020

<sup>2</sup> Pete Pattavina, biologist with the U.S. Fish and Wildlife Service Georgia Field Office. January 29, 2021

Oklahoma (14,000 overwintering bats; 2018 survey) and Caney Branch Hollow in Tennessee (32,400; 2016 survey). Populations in major hibernacula conservatively comprise individuals (males and females) from dozens of summer roosting populations across the range, including most if not all Priority 1 and 2 caves. If maternity and bachelor colonies are protected and populations are increasing, hibernacula surveys should reveal that increase; and the intention behind Criterion 2, which is to make sure that maternity colonies are stable and increasing, can be assessed by reviewing population trends at major hibernacula.



**FIGURE 3.** Number of gray bats in known major hibernacula, based on 2019 survey data (USFWS, unpublished data, 2021). The 2019 range-wide population estimate is 5,405,385, and 5,274,060 of bats range-wide roost in the major hibernacula. Thus, we estimate that approximately 98% of gray bats occur in just 15 major hibernacula.

Additionally, to determine if population trends were discernable at the state level, we conducted a population trend analysis for summer caves with available survey data. We included sites that were surveyed at least 4 times from 2000 to 2020. The methods section, below, includes detailed information on site selection, and even greater detail on the analysis is provided in Appendix B. Finally, we determined how many Priority 1 and non-Priority designated (but Biologically Significant) maternity sites are protected in each state.

In summary, instead of relying only on five years of surveys from Priority 1 maternity colonies to demonstrate stable or increasing trends, we:

1. Analyzed population trends over a period of 20 years for 14 hibernacula<sup>1</sup>, which are occupied by bats from Priority 1, Priority 2 and other Biologically Significant sites.

<sup>1</sup> Rattling Pit Cave is a major hibernaculum but there are only 2 winter surveys available from this site, so it was not included in the analysis.

2. Analyzed population trends over a 20-year period at a total of 79 summer sites, which include Priority 1, 2, and other Biologically Significant sites.

### **Population Trend Analysis - Methods**

Survey data for both hibernacula and summer roost sites were screened for suitability before inclusion in the population trend analyses. We excluded sites that either had too few counts for modeling (<4) or too few bats to be considered informative (<1,000). Survey data that were deemed unreliable by the surveyors were also excluded. The 79 summer sites included in the analysis consist of a mix of 70 confirmed and in some cases presumed maternity colonies and 9 sites that are considered to be occupied by bachelor or mixed use (adult male and female) colonies. Regardless of maternity, bachelor, and mixed-use status, summer roost data were split by survey month into pre-volancy<sup>1</sup> and a post-volancy sets to control for seasonal bias in emergence estimates at maternity and mixed-use sites. We did not conduct two separate analyses for maternity and bachelor colonies because winter survey data are also comprised of a mixture of both adult females, males, and young of the year and also because some sites do not have definitive sex assignments. In June and July of 2021, all sites harp trapped in Missouri and one in Indiana resulted in captures of a large number of both adult males and females, indicating that surveyed caves that support maternity colonies may also support bachelor populations. Lastly, surveyor information and spatial data were used to identify cave complexes that likely share a population among years<sup>2</sup>. If sites were fewer than 5 miles apart, they were considered as part of a complex unless biologists familiar with the site indicated the sites should not be grouped. Counts from sites within a complex were then combined into site-weighted composites that were modeled as separate data series (see Appendix B for information on site-weighted composites, and Table B1 for complex specific weights).

After screening, data were tested for population trends at the range-wide, state, and site / complex level. We employed both a nonparametric test (Mann-Kendall test<sup>3</sup>; Kendall 1976) and mixed linear models. The linear models were fitted to each data set, and the best-fitting model was selected using Akaike Information Criterion with a correction for small sample sizes (AICc; Burnham and Anderson 1998). Differences in survey method (e.g., direct visual counts, density by surface area estimates) were included in the linear models as method weights, to express the relative confidence in the associated count (see Table B2). For example, a direct visual count of 150 bats would be considered more

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<sup>1</sup> Pre-volancy represents the period during which young are present in the cave but have not developed the ability to fly. Post-volancy is the period during which juveniles can fly, and thus are included as part of the emergence counts. In many cases, the cutoff for pre-volancy was July 1 but the date used was ultimately the discretion of biologists familiar with the site.

<sup>2</sup> Erroneous trend conclusions could be made regarding the population trend for a cave if its population was assessed without consideration of the whole complex. For instance, a cave could appear to have very high numbers one year and low the next, giving the appearance of a decline in the population, but the change may be due to the result of movement of bats between nearby (within five miles) caves from year to year. Such fluctuations can be accounted for by grouping caves into known complexes (Thogmartin et al. 2012).

<sup>3</sup> The Mann-Kendall test has very low data requirements but low test power, while mixed linear models require a larger data set but yield more dependable results due to the inclusion of both fixed and random effects.

accurate than a population estimate of 15,000 bats based solely on the surface area of freshly accumulated guano. Further details on analysis methods, including method weights, are available in Appendix B.

## Population Trend Analysis - Results

The following were included in the analysis: 14 major hibernacula and 79 summer sites, of which 70 are maternity colonies and 9 bachelor/mixed use. Good coverage of colonies across the range was included in the analysis through the inclusion of nearly all the largest Biologically Significant Category 1 summer colonies and more than half of the Biologically Significant Category 2 smaller colonies (see Appendix B for the list of sites included in the analysis). Although there were differences in significance among tests, there were no conflicting trends between the nonparametric Mann-Kendall test (MK) and mixed linear model (LM) test results. Because the linear model results are generally more reliable than the nonparametric, we primarily used the linear model results to determine population trends.

Rationales for the population trend results are described below with the trends summarized in Table 3. An overall trend was also assigned to the gray bat range-wide and within each state based on the hibernacula and summer roost trends (Table 4). Additional results are available in Appendix B. Where no significant trend was detected, the absence of a trend might either indicate that the population remained relatively stable, or that the variance of the data was too high to yield a reliable estimate; this is discussed in the summaries below.

**Range-wide: Overall trend: increasing.** There is a strongly significant increasing trend in the hibernacula LM ( $p = 0.002^1$ ). The data indicate that the hibernacula populations have increased by an average of 148.8% from 2000 to 2020. There is also a significant positive trend ( $p = 0.043$ ) in the summer sites as shown in the pre-volant MK. The pre-volant dataset indicates generally stable populations at most sites, with the 2 most populous sites (by a large margin; Bellamy Cave (TN), Sauta Cave, (AL)) showing increasing trends significant at the site level in both cases). The post-volant data exhibited a similar stable baseline, with Sauta Cave again showing much greater counts but with no significant trend. Figure 4(a-d) depicts range-wide plots with fitted linear models for hibernacula, pre-volant and post-volant data. Because Fern Cave has over 1/4<sup>th</sup> of the gray bat population but only 3 surveys have been conducted, we present the findings both with and without Fern Cave.

**Alabama: Overall trend: inconclusive.** Because the hibernaculum Fern Cave was treated as part of a complex in Tennessee (Fern Cave and Hubbards Cave), no hibernacula estimates were modeled for the state. If Fern Cave was treated as an Alabama site, the hibernacula trend would be strongly positive based on this site alone. However,

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<sup>1</sup> In statistical testing, the p-value refers to the probability of obtaining test results as extreme as the results actually observed, under the assumption that the null hypothesis is correct, meaning that there is no relationship between variables being studied and, in the case, here, there is no discernable population trend. A very small p-value means that such an extreme outcome would be very unlikely under the null hypothesis.

there are only 3 population estimates available, and these are known to represent partial counts since bats are known to occur in inaccessible parts of the cave. Additionally, two of the three estimates are not considered highly reliable. Though the summer data for the bachelor colony in Sauta Cave indicate a stable baseline, observation of greater numbers does not result in a significant positive trend.

**Arkansas: Overall trend: increasing.** The statewide hibernacula complex (Cave Mountain Cave, Blanchard Springs Cave and Bonanza Cave) shows a highly significant increasing trend. The positive MK result for the pre-volancy period appears to be driven by a single high count at the bachelor colony at Blanchard Springs Cave and thus should not be considered as highly reliable. Both summer count sets give the impression of highly dispersed data rather than of stable populations. However, there are no indications that the highly significant increasing hibernacula population trends are unreliable; therefore, we consider the Arkansas population to be increasing.

**Georgia: Overall trend: possibly increasing.** No major hibernacula are known to exist in the state. Pre-volant counts from the only 2 caves included in the analysis (Chickamauga Creek Cave and Frick's Cave) show a significant positive trend in the MK test only, although this trend is not significant in the ML ( $p = 0.072$ ). Although the 2 caves are considered too far apart to be treated as a complex, the relative dynamics of the counts among years suggests that they likely represent a complex. However, treatment as a complex would yield a similarly non-significant trend result (data not shown). Post-volant counts are very sparse (5 counts only) and no trend is discernible. Given these considerations, there is weak evidence that the population might be increasing.

**Indiana: Overall trend: increasing.** No major hibernacula are known in the state. The trend estimate is based on post-volant population records from a single maternity site (Sellerbury Quarry Cave) that show a strong increase in population size between 2000 and 2017. The fitted LM for the entire post-volant period shows a highly significant trend ( $p = 0.01$ ).

**Kentucky: Overall trend: increasing.** The statewide hibernacula complex (Jones Cave, Jesse James Cave and Coach Cave) shows a highly significant increase ( $p = 0.008$ ). Every major maternity colony in the state is included in the analysis. While no state-level trend is discernible in the highly dispersed summer data, the result based on hibernacula appears reliable.

**Missouri: Overall trend: inconclusive.** The hibernacula data are inconclusive, consisting of a 3-site complex (Mose Prater Cave, Martin Cave and Bat Cave in Shannon County) and the single-site Coffin Cave, both of which show smaller count fluctuations but appear stable in the longer term. Pre-volant data are widely dispersed, and include a baseline of relatively stable sites and a strong increase at Mary Lawson Cave. Although the post-volant MK test is significant, the linear model does not show a trend. Based on these considerations there is no consistent population trend for the state. It should be noted that based on regular visits to the hibernacula in the state, the Missouri Department

of Conservation considers overwintering populations in their hibernacula to be generally stable and not decreasing<sup>1</sup>.

**Oklahoma: Overall trend: possibly decreasing.** There are no major hibernacula in the state. Most records are from the post-volant period, where the MK test shows a significant downward trajectory ( $p = 0.019$ ). These data are moderately dispersed (CV 48%). Data fitted to the linear model do not show a significant downward trend but visually suggest a downward trajectory for the post-volant period. Bats from Oklahoma likely overwinter in nearby Arkansas hibernacula, which have a significant positive trend. However, the proportion of Oklahoma bats that make up the Arkansas hibernacula is unknown. Therefore, we cannot exclude the possibility that summer colonies in Oklahoma are declining.

**Tennessee: Overall trend: increasing.** The positive hibernacula trend is strongly significant. This trend is partly driven by the inclusion of Fern Cave (AL) but not dependent on it - a model without this site still shows a significant trend ( $p = 0.02$ , data not shown). Pre-volant counts show no significant increase despite the increasing trend in the Bellamy Cave, which influences the pre-volant counts. Post-volant counts show a non-significant decreasing MK trend ( $p = 0.119$ ). In addition to the trend being non-significant, post-volant counts are very low in magnitude compared to hibernacula estimates (modeled population estimates of 3,000 to 12,000 bats in post-volant estimates, as compared to 185,000 to 573,000 bats in hibernacula), and we consider this insufficient evidence to contradict the hibernacula trend estimate.

**Virginia: Overall trend: inconclusive.** No hibernacula are known in the state. There is only 1 site for which sufficient data for analysis were available (Bristol Culvert). This maternity site has 3 pre-volancy and 5 post-volancy records with neither time period showing a significant trend.

**Complexes and Individual Sites:** Missouri-1 and Tennessee-1, and Coffin Cave (MO), show no significant trends. Two Tennessee hibernacula sites also function as maternity colonies and had pre-volancy survey records. Of these, Pearson Cave shows no significant trend in the summer counts, while those for Bellamy Cave confirm the highly significant positive trend in hibernacula counts. For more information on this separate complex-level analysis that groups nearby caves, see the Methods section.

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<sup>1</sup> Shelly Colatskie and Anthony Elliot, Missouri Department of Conservation, January 2021

**TABLE 4.** Population trend results from the Mann-Kendall and linear model tests for the gray bat range-wide and by each state from 2000-2020. Trends are reported for hibernacula, pre-volant summer roosts, and post-volant summer roosts, with an overall trend assigned.

	<i>Hibernacula</i>		<i>Summer sites pre-volant</i>		<i>Summer sites post-volant</i>		<i>Overall trend</i>
	<i>Mann-Kendall</i>	<i>Linear model</i>	<i>Mann-Kendall</i>	<i>Linear model</i>	<i>Mann-Kendall</i>	<i>Linear model</i>	
<b>Range-wide</b>	* incr	** incr	* incr	no trend	no trend	no trend	incr
Alabama	NA	NA	no trend	no trend	no trend	no trend	no trend
Arkansas	** incr	** incr	no trend	no trend	no trend	no trend	incr
Georgia	NA	NA	** incr	* incr	NA	no trend	poss. incr
Indiana	NA	NA	NA	NA	* incr	** incr	incr
Kentucky	* incr	** incr	no trend	no trend	NA	NA	incr
Missouri	no trend	no trend	no trend	no trend	** incr	no trend	no trend
Oklahoma	NA	NA	no trend	no trend	* decr	no trend	poss. decr
Tennessee	no trend	** incr	no trend	no trend	* decr	no trend	incr
Virginia	NA	NA	NA	no trend	no trend	no trend	no trend

**Legend:**

\*: test  $p \leq 0.1$

\*\* : test  $p \leq 0.01$

**no trend:** no significant test result. Where no significant trend was detected, the absence of a trend might either indicate that the population remained relatively stable, or that the variance of the data was too high to yield a reliable estimate.

**NA:** no test applied at this level due to insufficient data or inapplicable site category

**incr:** significant positive trend

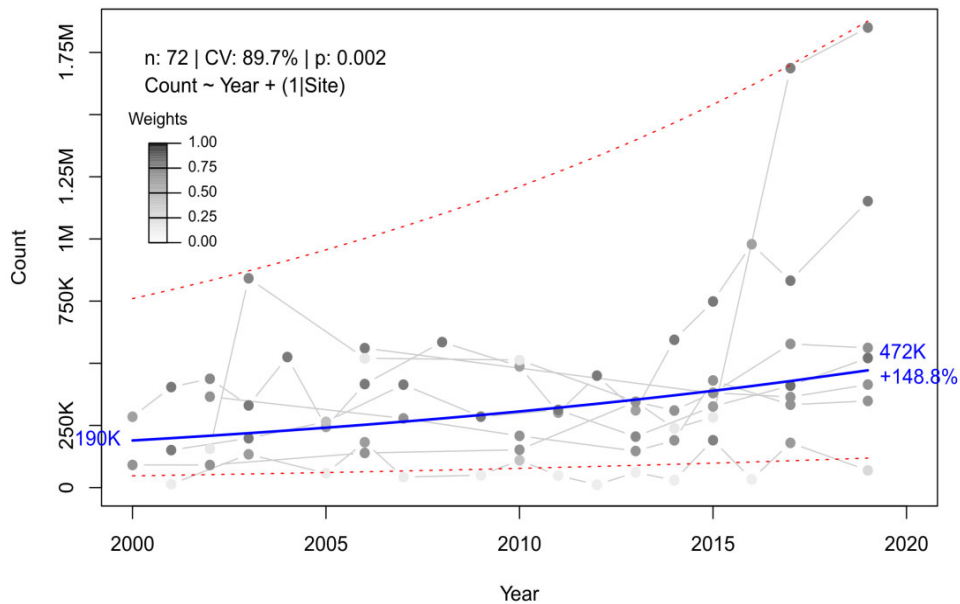
**poss.incr.:** possible positive trend

**poss.decr.:** possible negative trend

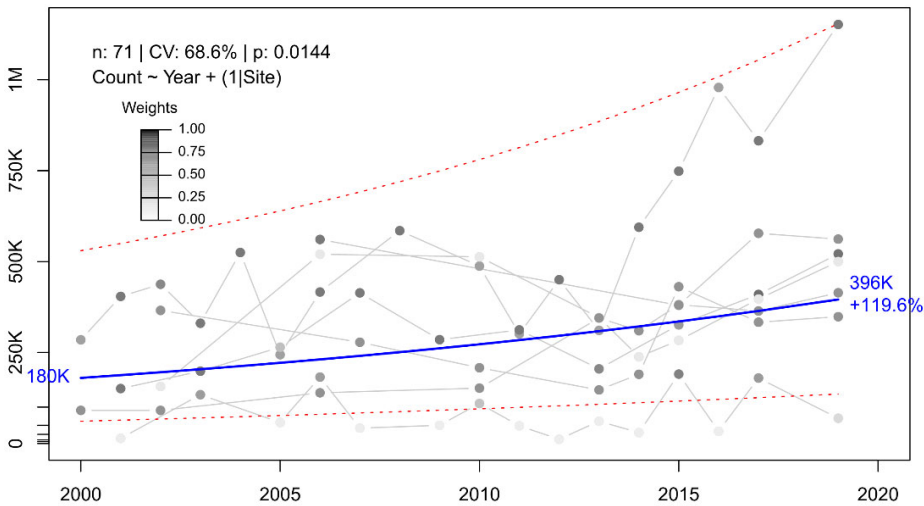
**decr:** significant negative trend

**FIGURE 4.** Number of individuals counted range-wide at (a-b) hibernacula, (c) pre-volant summer roost sites, and (d) post-volant summer roosts. Individual regression lines in each figure represent count data from individual sites included in the analysis. Counts are shaded by assigned survey method confidence weights (combined method and within-complex weights), with darker shade indicating greater weight. The blue line depicts the predicted regression line from the linear mixed model, and blue text represents predicted starting and ending population sizes and percent change in population size over the modeled period. Red dashed lines represent 95% confidence intervals of predicted values. Note that the model (blue line) predicts the mean population size and not the sum of bats across all the sites (the sum will almost always be higher).

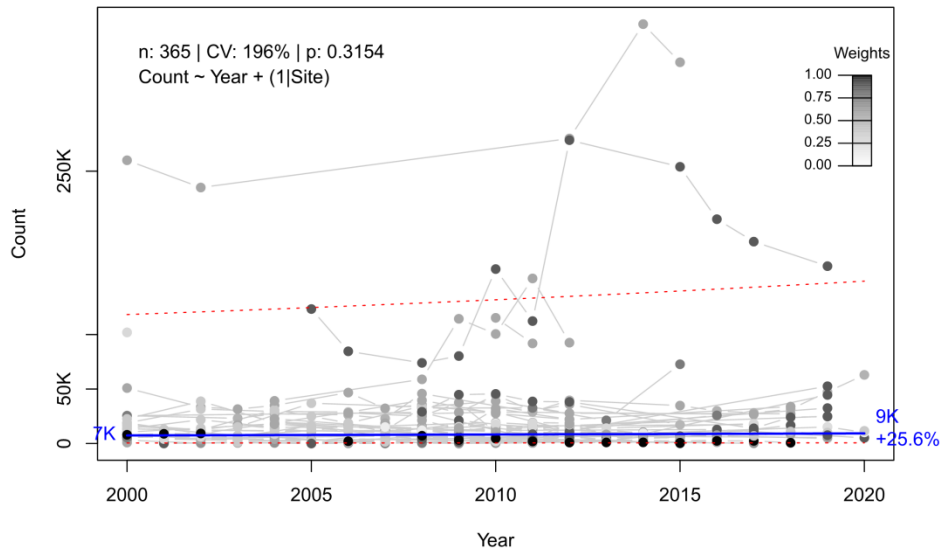
**4(a).** The number of individuals counted range-wide at hibernacula, including Fern Cave.



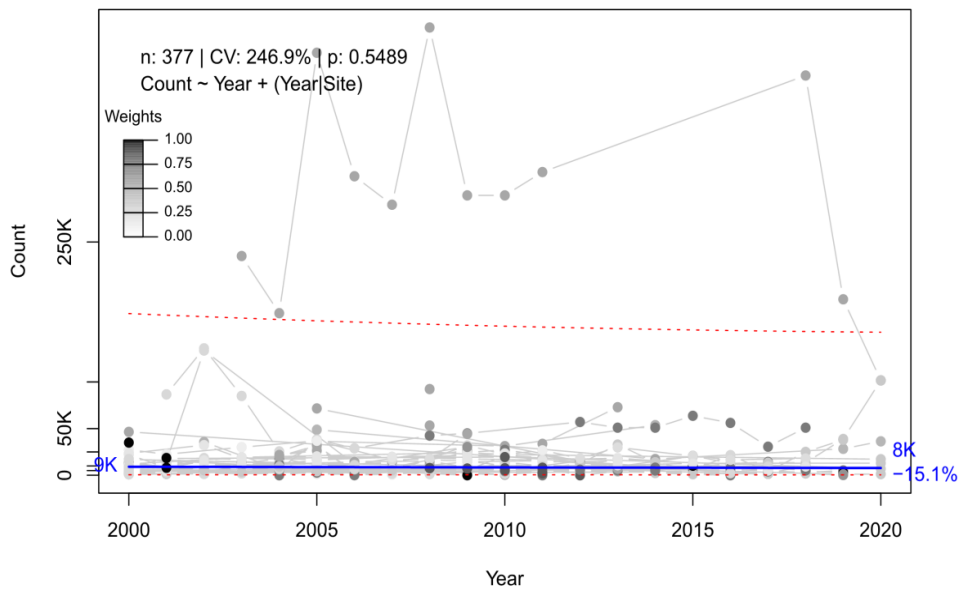
**4(b).** The number of individuals counted range-wide at hibernacula, excluding Fern Cave.



4(c). The number of individuals counted range-wide during the summer pre-volant period.



4(d). The number of individuals counted range-wide during the summer post-volant period.



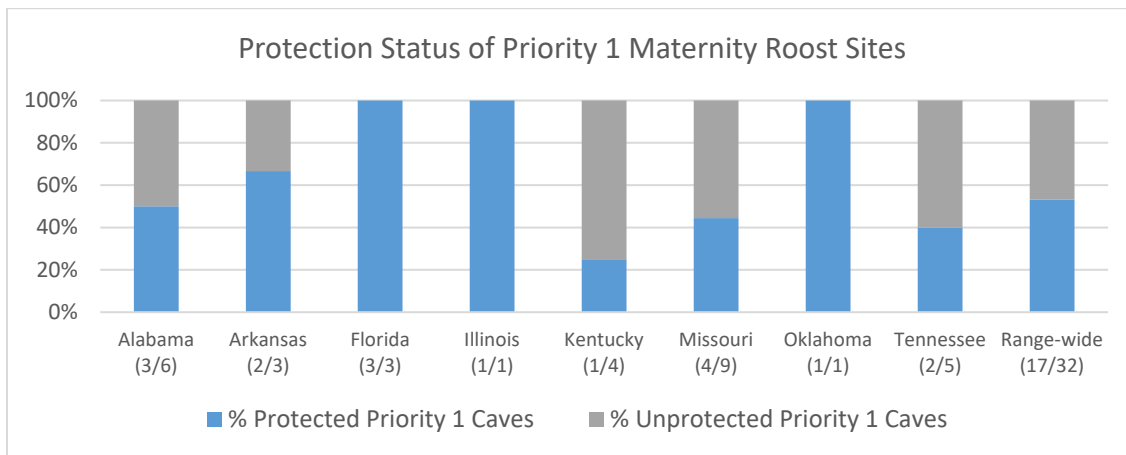
**Status of Reclassification Criterion 2: ACHIEVED.**

We consider the intent of this criterion to be met even though consistent monitoring of Priority 1 maternity caves did not occur such that we could document stable or increasing populations at 75% of Priority 1 maternity caves over a 5-year period. Because bats in major hibernacula represent an estimated 98% of gray bats range-wide, we included data from the 14 major hibernacula and 79 priority 1 maternity caves to analyze population trends from 2000 to 2020. The range-wide hibernacula and summer pre-volant data indicate that gray bat populations are stable or increasing. This alternative method directly addresses survival and reproduction of individuals within summer maternity colonies and ensures that redundancy of stable populations is addressed throughout the range.

### 2.2.3 Summer Roost Colony Protection Status Assessment

Although no protection-based criteria were assigned to Priority 1 summer roost sites, the Recovery Plan outlines priority tasks for 32 Priority 1 summer caves. Therefore, in addition to the population trend analyses, we assessed how many Priority 1 and other Biologically Significant summer caves have been permanently protected. As stated in Section 2.1, cave protection involves ensuring minimal disturbance to bats during the summer season. To be considered protected, caves may be publicly or privately owned. However, for privately-owned caves, there must be a long-term voluntary landowner agreement, such as a stewardship plan, conservation easement, habitat management plan, or memorandum of agreement that protects the maternity roost in perpetuity. Caves may be physically protected, meaning the cave could be protected from human entry by a bat gate, chain link fencing, gates across farm roads, alarm systems, and/or a landowner/manager present at access points to the cave. Caves could also be considered protected due to their location, meaning that the cave is not accessible due to the ruggedness of terrain, difficult to enter (e.g., requires repelling into a steep vertical pit, has high water levels at the mouth and would require swimming to enter), or the cave is very difficult to find. Conversely, a site may not be considered protected despite having physical protection and/or being on publicly owned land if the site has recurring trespassing and gate/fence breaching issues.

At the time the Recovery Plan was written, Kansas and Virginia did not have large enough populations to have designated Priority 1 sites. The Recovery Plan authors considered these 32 sites to be the most important maternity colonies across the range to protect from disturbance. The full list of priority actions and their status (i.e., protected or not protected) for each Priority 1 site is provided as Table A1 in the Appendix and summarized in Figure 5. Range-wide, 17 of 32 (53%) Priority maternity sites have been protected (Figure 5).



**FIGURE 5.** The protection status of Priority 1 (P1) gray bat maternity colony roosts. The number of total and protected roosts in each state is depicted below the name (protected/total) and displayed as a percentage in the graph. Georgia, Kansas, Virginia and North Carolina sites were not given P1 status in the Recovery Plan. Priority 1 designations are considered outdated and have been replaced with re-ranked Category 1 Biologically Significant sites (Figure 6).

As previously stated, some Priority sites are no longer occupied, have very low numbers, or sites not included in the 1982 Recovery Plan Priority assignments now have large populations. We therefore organized gray bat summer sites into 3 Biologically Significant categories based on their recently estimated population sizes (Table 5). The Recovery Plan includes Biological Significance assignments based on population size, but these assignments are outdated. The new category ranges were created based on a visual review of the distribution of population sizes for caves in each state. We then assigned each cave to a category using the mean population estimate values spanning 2010 to 2020. If 4 or more survey data were not available from this timeframe, we took the mean of any surveys from 2000 to 2020. The category assignments for caves were then provided to States to review and adjusted as needed based on their knowledge of the properties, cave locations, and surveys. Ultimately, 46 summer sites were designated as having the highest Biological Significance (Category 1), 49 as Category 2, and all remaining sites were placed in Category 3. Category 3 includes summer roost sites that fall within the ranges provided for each state in Table 5 as well as any sites that require further investigation (e.g., sites whose population sizes need to be confirmed). The list of Category 1 and 2 summer roosts is provided in Table 6. The general locations are provided in Figure 7. Category 3 caves are not depicted; all caves not included in Table 6 should be considered Category 3 and all cave assignments can be adjusted in the future as surveys are conducted.

**TABLE 5. Population-based Categories for Biologically Significant Summer Roost Sites.** The recommended Category 1-3 ranking system assignments for caves based on the estimated number of gray bats that occupy the summer roost (maternity or bachelor). Numbers not in bold represent the ranges provided in the 1982 Recovery Plan, whereas numbers in bold represent recommended updated ranges. NA = Recovery Plan did not designate any caves for the state in the Recovery Plan, likely because populations in the state were unknown to occur in 1982.

State	Category 1	Category 2	Category 3
Alabama	>50,000; 1,000 <sup>1</sup> <b>&gt;25,000</b>	5,000 - 50,000 <b>5,000 to 25,000</b>	<5,000
Arkansas	>1,000 <b>&gt;10,000</b>	500 - 1,000 <b>5,000 - 10,000</b>	<500 <b>&lt;5,000</b>
Florida	>1,000	500 - 1,000	<500
Georgia	N/A <b>&gt;5,000</b>	N/A <b>1,000 - 5,000</b>	N/A <b>&lt;1,000</b>
Illinois	NA <b>&gt;5,000</b>	NA <b>1,000 - 5,000</b>	NA <b>&lt;1,000</b>
Indiana	NA <b>&gt;5,000</b>	NA <b>1,000 - 5,000</b>	NA <b>&lt;1,000</b>
Kansas	>1,000	500 - 1,000	<500
Kentucky	>40,000 <b>&gt;20,000</b>	1,000 - 10,000 <b>5,000 - 20,000</b>	<5,000
Missouri	>10,000 <b>&gt;25,000</b>	1,000 - 10,000 <b>5,000 - 25,000</b>	<1,000 <b>&lt;5,000</b>
North Carolina	NA <b>&gt;5,000</b>	NA <b>1,000 - 5,000</b>	NA <b>&lt;1,000</b>
Oklahoma	>1,000 <b>&gt;10,000</b>	500 - 1,000 <b>5,000 - 10,000</b>	<500 <b>&lt;5,000</b>
Tennessee	>50,000; 10,000 <sup>2</sup> <b>&gt;10,000</b>	5,000 - 50,000 <b>5,000 - 10,000</b>	<5,000
Virginia	N/A <b>&gt;5,000</b>	N/A <b>1,000 - 5,000</b>	N/A <b>&lt;1,000</b>

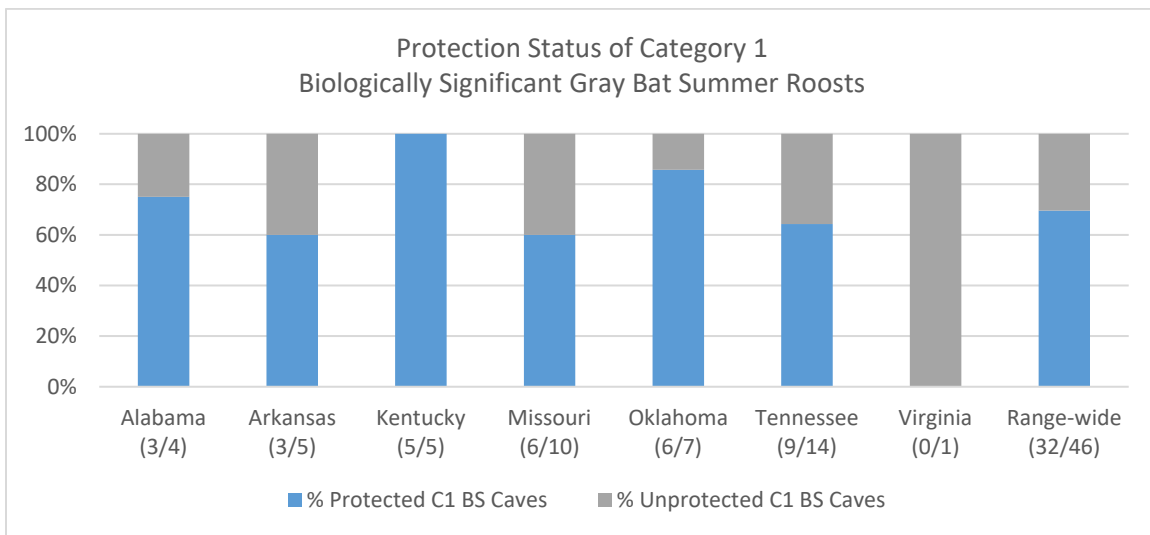
<sup>1</sup> 50,000 in northern Alabama, 1,000 in southern Alabama.

<sup>2</sup> 50,000 west of the Cumberland Plateau, 10,000 east of the Cumberland Plateau.

**TABLE 6.** Biologically significant cave assignments for Category 1 and 2 summer roost sites in each state. The general locations of these roosts are provided in Figure 7.

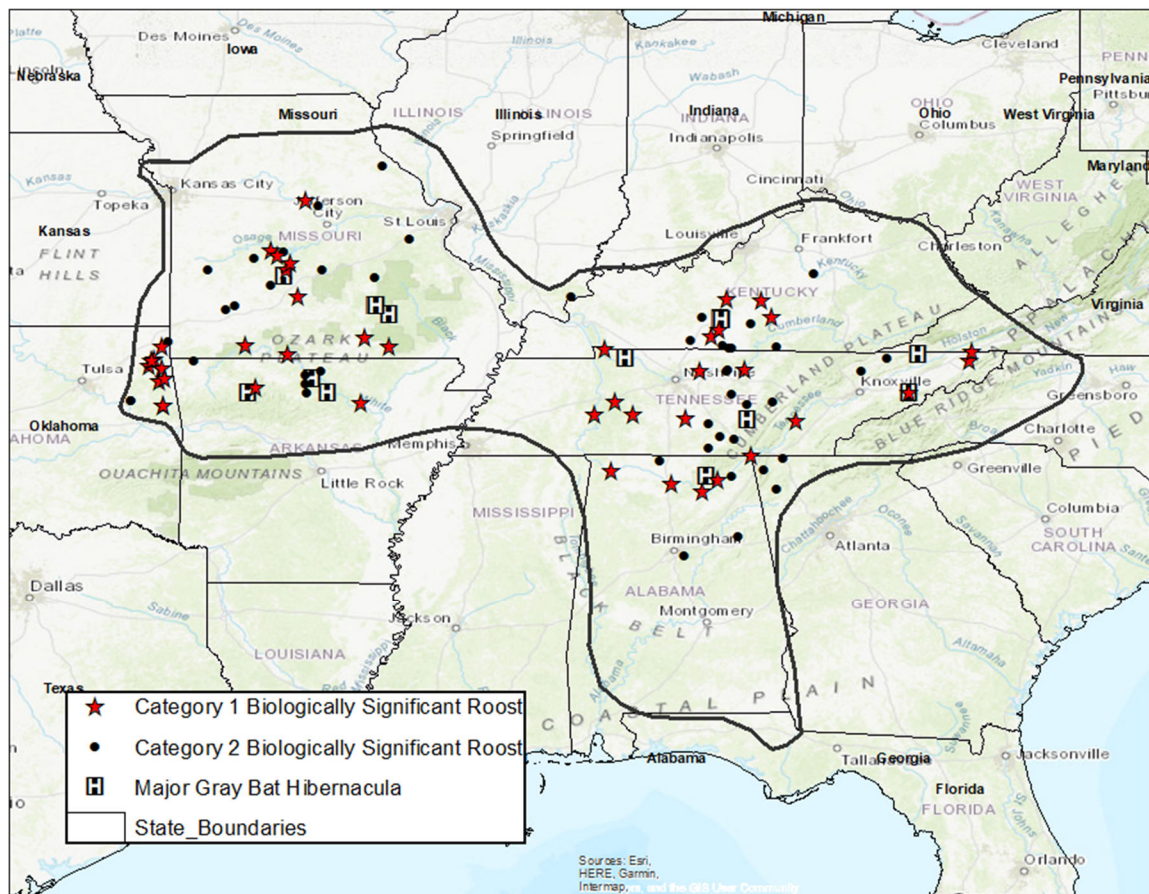
STATE	Colony Population Size (Category 1)	Biological Significance Category 1	Colony Population Size (Category 2)	Biological Significance Category 2
Alabama	>25,000	Cave Springs Cave	5,000 to 25,000	Indian Cave
		Hambrick Cave		Weaver Cave
		Key Cave		Coon Track Cave
		Sauta Cave (bachelor colony)		Anderson Cave
Arkansas	>10,000	Bone Cave	5,000 to 10,000	Big Creek Cave
		Buzzard Roost		Crystal Cave
		Horseshoe Cave		Huffman Cave (bachelor colony)
		Horsethief Cave		Summer Cave
		Logan Cave		Old Joe Cave
		Blanchard Springs Cavern (bachelor)		Surprise Pit Cave
Georgia	>5,000	<i>No sites in this range</i>	1,000 to 5,000	Chikamauga Creek Cave
Illinois	>5,000	<i>No sites in this range</i>	1,000 to 5,000	Frick's Cave (bachelor and maternity)
				Lowrey Cave (bachelor colony)
				Cave Springs Cave
Kentucky	>20,000	<i>No sites in this range</i>	5,000 to 20,000	Buzzard Roost/Robertson Complex
				Caney Branch Cave
				Carpenter Cave
				Overstreet Cave
				Payne/Temple Hill Saltpeter Cave
				Smoky Cave
				Sulphur Creek Cave
Watt Cave				
Missouri	>25,000	<i>No sites in this range</i>	5,000 to 25,000	Bat Cave (Dent County)
				Low Water Bridge Cave
				Bat Cave (Pulaski County)
				Beck Cave
				Buffalo Quarry
				Devil's Ice Box
				Grandpa Chipley Cave
				Franford Cave
				El Dorado Spring Sewer
				Norman Lead Mine
				Stinson Cave
Oklahoma	>10,000	<i>No sites in this range</i>	5,000 to 10,000	Dressler Cave
				Shifflet Cave
				Spavinaw Bat Cave
Tennessee	>10,000	<i>No sites in this range</i>	5,000 to 10,000	Bridgewater Cave
				Caney Hollow Cave
				Cripps Mill Cave
				Piper Cave
				White Buis Cave
				Jaco Cave
				Oaks Cave
				Rose Cave
				Trussel Cave
				Woods Dam
				Yell Cave
				Indian Cave
Virginia	>5,000	Bristol Culvert	1,000 to 5,000	<i>No sites in this range</i>

Biologically Significant Category 1 roost sites are most synonymous with Priority 1 maternity sites in that they both include the largest colonies across the range. Biologically significant colonies in both Category 1 and 2 are spread out across the range, indicating redundancy of populations. Thirty-two of 46 (70%) Category 1 Biologically Significant roost sites across the gray bat’s range are considered permanently protected (Figure 6). Four of these sites are bachelor colonies. All states have protected 60% or more of their Category 1 summer sites except Virginia, whose only colony site is a culvert above a roadway that cannot be protected. The Missouri Field Office and the Missouri Department of Conservation also recently provided funding to gate privately owned Toby Cave, which will raise the number of protected Category 1 sites from 32 to 33 of 46 sites, for a total of 72% protected sites range-wide. Therefore, we consider the largest summer colonies across the range to have a high degree of protection in each state and range-wide.



**FIGURE 6.** The protection status of Category 1 (C1) Biologically Significant gray bat summer roosts (42 maternity and 4 bachelor colonies). The figure does not include hibernacula, the protection status of winter caves was assessed separately. The number of total and protected roosts in each state is depicted below the name (protected/total), and displayed as a percentage in the graph. Florida, Georgia, Kansas, and Illinois do not have C1 Biologically Significant sites.

Permanent Protection of Priority 1 and Biologically Significant Category 1 Summer Sites: Thirty-two of 46 (70%) Category 1 Biologically Significant roost sites across the gray bat’s range are considered permanently protected (Figure 6). All states have protected 60% or more of their Category 1 sites except Virginia, whose only site is a culvert above a roadway that cannot be protected. Therefore, we consider the largest summer colonies across the range to have a high degree of protection in each state and range-wide.

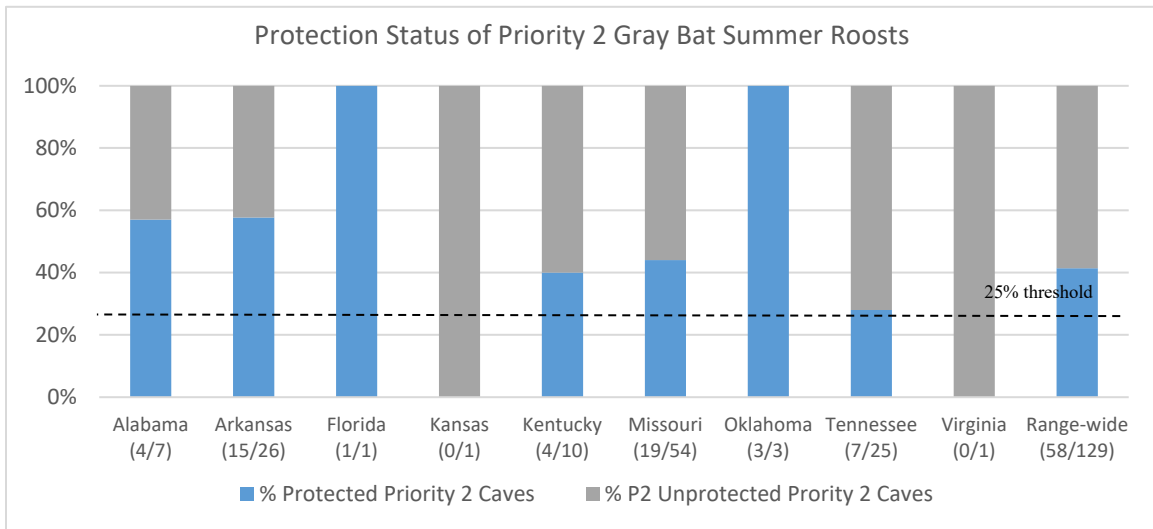


**FIGURE 7.** The general locations of Biologically Significant summer caves and major hibernacula.

**2.2.4. Criterion 3: Permanent protection of  $\geq 25\%$  of Priority 2 caves in each state.**

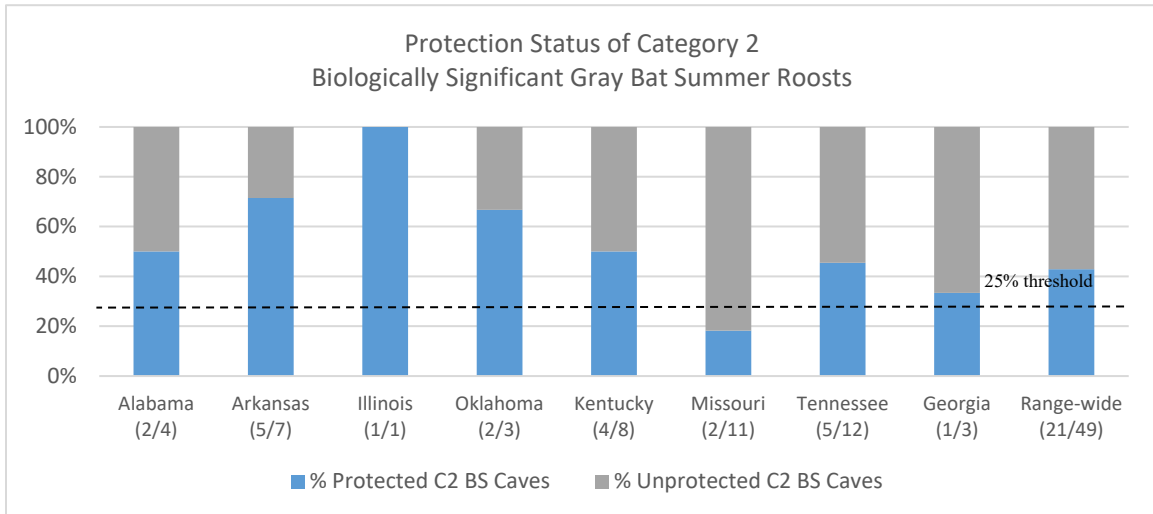
There are 129 Priority 2 sites listed in the Recovery Plan (see Table 2 for site specific assignments). The Plan recommended a variety of actions for caves, ranging from surveys, cooperative agreements and signage to gating and acquisition of properties surrounding caves. As noted in Section 2.1.4, some Priority 2 caves have long been abandoned or have such low populations that they are no longer considered biologically significant (e.g., Fears Cave, River Cave, and Sneads Bat Cave in Florida; Cat Hollow Cave, Carrol Cave, and Lewis and Clark Cave in Missouri). Conversely, caves that were a low priority or were not occupied by bats at time of listing now warrant protection and monitoring due to their significant populations. The status changes are now accounted for through the updated Biological Significance ranking system described in Section 2.1.3.

To assess Criterion 3, we determined the number of protected Priority 2 sites. Overall, 58 of 129 (45%) Priority 2 sites are considered protected (see Table 2 for a list of the sites or Table A1 for site specific protection status). The Recovery Plan recommended protecting a minimum of 25% of Priority 2 sites in each state. Except for Kansas and Virginia, all states have protected  $\geq 25\%$  of their Priority 2 sites. While Kansas and Virginia have not met the 25% threshold, both states each have only 1 Priority 2 site, and each site has a relatively small number of bats. Lack of protection of these sites is not expected to have a major impact on the recovery of gray bats.



**FIGURE 8.** The protection status of Priority 2 gray bat roosts (maternity/bachelor colonies). The number of total and protected roosts in each state is depicted below the name (protected/total) and displayed as a percentage in the graph. Georgia, Illinois and North Carolina sites were not given P2 status in the Recovery Plan.

However, as stated in Section 2.1.3, an assessment of Biologically Significant roosts is a more appropriate way to assess the protection status of caves. Category 2 Biologically Significant caves are the most synonymous with Priority 2 caves due to their significant but lower bat population sizes. Range-wide, 21 of 49 (43%) Category 2 Biologically Significant caves have been permanently protected (Figure 9). Each state except Missouri has protected at least 25% of their Category 2 sites. The locations of Category 2 Biologically Significant Caves are provided in Figure 7.



**FIGURE 9.** The protection status of Category 2 (C2) Biologically Significant gray bat summer roosts (maternity and bachelor colonies). The figure does not include hibernacula, the protection status of winter caves was assessed separately. The number of total and protected roosts in each state is depicted below the name (protected/total), and displayed as a percentage in the graph. Florida, Kansas, Virginia and North Carolina do not have C2 Biologically Significant sites.

### **Status of Reclassification Criterion 3: NEARLY ACHIEVED.**

This criterion is meant to address threats to smaller but important summer colonies and to ensure that this criterion is addressed throughout the range (i.e., ensures population redundancy). The Recovery Plan recommended protecting a minimum of 25% of Priority 2 sites in each state. Based on our review, 58 of 129 (45%) Priority 2 sites are considered protected (Figure 8; Table A1), with Kansas and Virginia each having one summer roost that is not protected. While these two states do not meet the 25% threshold, both states have only 1 Priority 2 site, and each site has a relatively small number of bats. Lack of protection of these sites is not expected to have a major impact on the recovery of gray bats. Range-wide, 21 of 49 (43%) of all Category 2 Biologically Significant caves have been protected (Figure 9). Each state except for Missouri has protected at least 25% of their Category 2 Biologically Significant sites. Missouri is one site from meeting the 25% recommended threshold. Based on the minimum protection threshold recommended in the Recovery Plan, protection of the second tier sites has been nearly met.

#### **2.2.5 Criterion 4: Documentation of stable or increasing populations at 25% of Priority 2 caves.**

The Recovery Plan team designated 129 Priority 2 caves that should be used in the basis for reclassification and delisting of the gray bat (Table A1). To meet Criterion 4, stable or increasing populations need to be documented at 25% of Priority 2 caves over a 5-year period in each state. This criterion cannot be assessed as recommended because few of the Priority 2 caves have been monitored annually, or for a consecutive 5-year period.

Because there are not enough data to assess if Criterion 4 has been met using the recommended measure, the population trend of Priority 2 colonies was assessed using the same alternate criteria as for Criterion 2 (population trends of Priority 1 colonies). As stated in Section 2.1.2, bats and young of the year in hibernacula represent individuals that have survived and successfully reproduced during the summer season. Populations in these few hibernacula conservatively comprise dozens of summer roosting populations across the range, including most if not all 176 Priority 1 and 2 caves. If maternity and bachelor colonies are stable or increasing, hibernacula surveys should reflect summer conditions, and the intention behind Criterion 4, which is to make sure that maternity colonies are stable or increasing, can therefore be assessed by reviewing population trends at major hibernacula.

Additionally, we conducted a population trend analyses for summer caves with data that were available. We included sites that were surveyed at least 4 times from 2000 to 2020. The methods section of this review includes detailed information on site selection. Finally, we determined whether 25% of Priority 1, 2 and other biologically significant caves are permanently protected in each state and range-wide. The methods used to complete these analyses are further described in Appendix B.

In summary, instead of relying only on five years of surveys from Priority 2 colonies to determine population trends, we:

1. Analyzed population trends over a period of 20 years for 14 major hibernacula, which are occupied by bats from Priority 1, 2 and other Biologically Significant summer caves.
2. Analyzed population trends over a period of 20 years at 79 Priority 1, 2, and Biologically Significant summer colonies.

The results of this analysis are provided in Section 2.1.2.

**Status of Reclassification Criterion 4: ACHIEVED.**

We consider the intent of this criterion to be met even though consistent monitoring of Priority 2 caves did not occur such that we could document stable or increasing populations at 25% of Priority 2 caves over a 5-year period. Because major hibernacula represent an estimated 98% of gray bats, including those from Priority 2 caves, we analyzed population trends at the 14 major hibernacula and 79 pre- and post-volant summer Priority 1, 2, and other Biologically Significant caves from 2000 to 2020. The range-wide hibernacula and pre-volant summer data indicate that gray bat populations are stable or increasing. This alternative method directly addresses survival and reproduction of individuals within both large and small summer colonies and because hibernacula include individuals from multiple states ensures that redundancy of stable populations is addressed throughout the range.

**2.2.6. Summary of Reclassification Criteria**

The four reclassification criteria are outlined in Table 9. Table 9 also summarizes the status of completion of the relevant measures. Criteria 1, 2, and 4 have been met outright or through alternate means, while Criterion 3 has nearly been met.

**2.3 Updated/New Information and Current Species Status**

Since the 2009 review, significant increases in observed number of bats at 2 new major hibernacula have been documented: Rattling Pit Cave in Tennessee and Martin Cave in Missouri. Rattling Pit Cave was surveyed in 2017 and found to have approximately 250,000 bats during a 2019 survey. A new section of Martin Cave in Missouri was surveyed in 2015 and found to have approximately 39,000 bats during a 2019 survey. Rattling Pit Cave is owned by the City of Newport, Tennessee and is considered protected; while Martin Cave is located within two private properties and is owned by two separate landowners. One entrance to Martin Cave is gated, but the second is neither gated nor protected and unauthorized cave entry is known to occur. Martin Cave is one of the less populated of the ‘major’ gray bat hibernacula across the range and accounts for only 1% of hibernating bats across the range. Even with documented disturbance, however, the population within the cave has increased from approximately 30,000 to 40,000 from 2015 to 2019.

**TABLE 9.** Recovery criteria and a summary of progress. In the Recovery Plan, Priority 1 actions were assigned to major hibernacula and their associated, important maternity colonies. Priority 2 actions were assigned to summer maternity, bachelor, or mixed-use roosts and hibernacula with fewer bats.

Reclassification Pathway		Relevant Measure	Current Status	Conclusion
Endangered to Threatened	Criterion 1	Permanent protection of 90% of Priority 1 hibernacula.	90% of Priority 1 hibernacula have been permanently protected. Additionally, 14 of the 15 (93%) most populous gray bat hibernacula have been protected. The only cave that is not protected has <1% of bats hibernating across these 15 caves.	Achieved; Alternate Criteria Used
	Criterion 2	Stable or increasing populations at 75% of Priority 1 maternity caves over a period of 5 years.	Trend analyses of the 14 most populous hibernacula and 79 summer colonies for which data are available show that gray bat populations are stable and increasing range-wide (148.8% increase in hibernacula) over the past 20 years (see Section 2.1.2 for trend analysis methods and results).	Achieved; Alternate Criteria Used
Threatened to Recovered	Criterion 3	Permanent protection of 25% of Priority 2 caves in each state.	58 of 129 (45%) Priority 2 caves have been permanently protected.  Based on more updated cave ratings, 32 of 46 (70%) Category 1 and 21 of 49 (43%) of Category 2 Biologically Significant caves across the gray bat's range have been permanently protected. However, < 25% of Category 2 caves have been protected in Missouri (2 of 12 or 17%).	Nearly Achieved; Based on Priority 2 Caves  Nearly Achieved; Based on Biological Significance
	Criterion 4	Stable or increasing populations at 25% of Priority 2 caves in each state.	Trend analyses of the 14 most populous hibernacula and 79 summer colonies for which data are available show that gray bat populations are stable and increasing range-wide (148% increase in hibernacula from 2000 to 2020).	Achieved; Alternate Criteria Used

### 2.3.1 Biology and Habitat

#### **New information on the species' biology, life history, threats and conservation:**

Although several thousand caves occur throughout the species' range, Tuttle (1979) found only 5 percent of available caves provided suitable gray bat winter habitat. Suitable hibernacula are typically deep, vertical caves with multiple entrances, good airflow, and temperatures between 5° and 11°C (42 to 52 °F) (Tuttle 1976b). Male and female gray bats typically hibernate together and return to the same caves or mines (or to small groups of caves or mines in close proximity) each summer (Tuttle 2003). However, because the number of caves meeting the required hibernacula conditions are limited,

gray bats have been recorded traveling hundreds of kilometers between summer and winter sites (Colatskie et al. 2018; Tuttle 1976a).

Unlike for hibernacula, gray bats appear to have some flexibility in their selection of summer roost locations, although most of the caves are typically close to a large body of water. Summer caves typically have restricted rooms or domed ceilings that trap body heat from thousands of clustered bats (Tuttle 1975). Since gray bats are known to travel long distances between summer and winter sites, the locations of summer roosts are likely only somewhat influenced by their distance to hibernacula. In spring, band recoveries have shown that gray bats can travel as far as 800 km (497 miles) between roosts (Elder and Gunier 1976), although it is unlikely that most bats travel this distance between winter and summer grounds since many maternity and bachelor colonies are <100 miles from their closest hibernacula. There are numerous band returns for distances in the 200-mile range (e.g., a 260-mile band recovery in Fern Cave, AL from a bat banded at Copper Creek Cave, VA; Holliday, pers. comm., 2021<sup>1</sup>).

While gray bats are primarily cave dwellers, colonies have been documented using a variety of human-made structures, including dams, mines, quarries, concrete box culverts, and crevices between concrete barriers in bridges. In one instance, gray bats have been documented using a bat house (Colaskie, pers. comm., 2020<sup>2</sup>). Their use of human structures is likely a relatively recent, possibly expanding practice. Colonies using artificial roost sites tend to occur at the edges of their range where suitable caves may not be as readily available. However, in some cases, artificial structures are chosen over nearby caves. At least two dams occupied by gray bats (1 in Missouri and another in Tennessee) are both protected from human disturbance and predators (Campbell, pers. comm., 2020<sup>3</sup>; Vona Kuczynska, pers. obs., 2020<sup>4</sup>). Additionally, Samoray et al. (2020) tracked two gray bats to live and dead trees that were used as diurnal roosts during migration in Madison County, North Carolina and Putnam County, Tennessee. Trees were not considered suitable habitat for gray bats in the past, and these novel observations warrant additional studies to better understand how often gray bats rely on forested habitats for behaviors other than foraging.

Examples of artificial roost sites along the edge of the range include at least 3 bridges in the western portion of North Carolina, 3 in Georgia, a culvert on the Virginia/Tennessee border and another in Georgia, as well as an underground storm sewer in western Missouri and another in eastern Kansas. Samoray (2020) describes additional examples of human-made structures used by gray bats. There are also numerous accounts of gray bats using bridges and culverts as stop-over sites during migration, indicating that use of artificial structures is not a phenomenon that is constrained to summer sites. Sasse (2019) observed gray bats using 21 of 164 checked bridges in Arkansas. Most bats were solitary individuals, and the majority were observed in the spring. More rarely, small hibernating populations also use artificial structures. For example, a small colony of gray bats

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<sup>1</sup> Cory Holliday, biologist with Tennessee Chapter of The Nature Conservancy. February 23, 2021.

<sup>2</sup> Shelly Colatskie, biologist with Missouri Department of Conservation, June 20, 2020

<sup>3</sup> Joshua Campbell, Wildlife Diversity Coordinator, Tennessee Wildlife Resources Agency September 11, 2020

<sup>4</sup> Vona Kuczynska, USFWS wildlife biologist with the Columbia Missouri Field Office, August 29, 2020

overwinters in the Lime Kiln Mine, Missouri (397 individuals, 2019 survey; USFWS unpublished data).

The locations of summer and winter colony sites have been well established, but migratory pathways between sites are unknown. The vast majority of gray bat banding projects were conducted from the 1930s through the 1970s, and many of the summer-winter site relationships were established from these studies. Numerous summer caves and 6 major winter hibernacula have been documented since the last major study; yet few attempts have been made to connect summer colonies to their winter hibernacula. Additionally, even less is known about land-use during migration (Gerdes 2016; Colatskie et al. 2018). We are aware of one study that used aircrafts to track three gray bats in Tennessee in 2019. The results indicated that bats generally flew in very straight lines and stopped over water to forage. Water and other land types did not seem to influence migration routes (Holliday, pers. comm., 2021<sup>1</sup>). Tracking efforts will continue in 2021, where gray bats will be tracked from spring to summer grounds in Tennessee (Campbell, pers. comm., 2020<sup>3</sup>).

An extensive literature set exists for the gray bat throughout its range. Many of the earlier studies addressed basic ecology, behavior and characterization of roost sites (e.g., Twente 1985; Tuttle 1975, 1976a, 1976b). Later studies focused on gray bat ecology, habitat requirements, behavior, population threats, and management. Since the 2009 review, more than 30 new scientific papers, theses and dissertations have been published that directly or indirectly relate to the gray bat and its conservation. A topical listing of articles published since 2009 is provided in Appendix A under the heading “Publication List”.

### **2.3.2. Abundance and Population Trends**

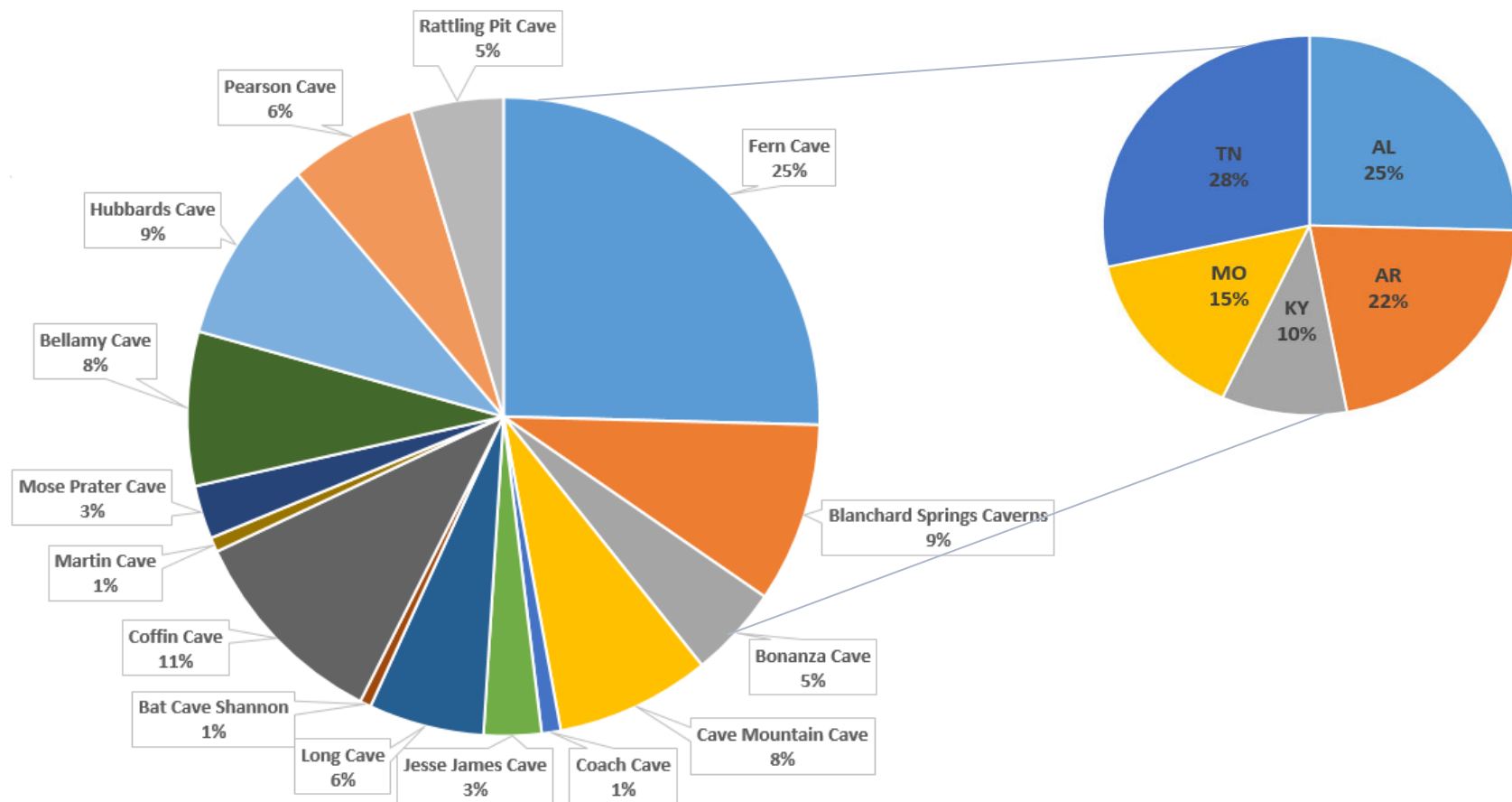
Gray bat winter population surveys are conducted every other winter (biennially) at most hibernacula across the species’ range, and every year for some hibernacula. In 2019, the Missouri Ecological Services Field Office requested survey data from each state within the range of the gray bat dating back at least to the year 2000. This data, some of which dated as far back as the 1960’s, was then used to develop a gray bat summer and hibernacula population database to generate biannual range-wide gray bat population estimates and to track population trends. The results of this data collection and analyses were subsequently utilized in calculations to assess achievement of recovery criteria related to population trends for this 5-year review.

The 2019 (most current) range-wide gray bat population estimate from hibernacula counts is approximately 5,306,905 bats (Table 8). The 2019 range-wide population increased 15% from the 2017 estimate of 4,504,520. The distribution of overwintering bats is provided in Figure 8. This estimate does not include a few smaller hibernacula that make up approximately 3% of gray bats (Figure 3). Including count data from much smaller hibernacula, the range-wide estimate for 2019 is likely between 5,306,905 and 5,405,385. For population trends at major hibernacula and summer sites, see Section 2.1.2.

**TABLE 8.** Population estimates for Priority 1 and Biologically Significant hibernacula surveyed since the 2009 5-Year Review. 1982 Recovery Plan Priority 1 hibernacula are marked with an asterisk. Empty cells indicate that no surveys were completed for the year, while zeros indicate that no bats were observed during the surveys.

State	Hibernacula (n = 15)	2010	2011	2012	2013	2014	2015	2016	2017	2019
AL	Fern Cave*								1,289,848	1,349,976
AR	Cave Mountain Cave	390,490	127,670	89,420	138,210	301,920	276,111	606,064	377,060	419,400
	Blanchard Springs Cavern	97,240	173,740	170,000	172,745	218,815	372,101	372,726	372,445	484,670
	Bonanza Cave*			190,910		73,780	100,470		82,841	248,000
FL	Old Indian Cave*	0	3			0	0	0	0	0
KY	Coach Cave		80,324		75,596		112,039		76,395	51,769
	Long Cave		11,920						153,000	313,357
	Jesse James Cave*		220,104		129,533		214,093		180,406	156,166
MO	Martin Cave						30,000		42,535	39,051
	Bat Cave		48,501	11,650	61,172	30,000	20,531		33,500	30,312
	*Coffin Cave						380,000		577,850	561,936
	Mose Prater Cave*	110,000					140,200		137,432	137,432 <sup>1</sup>
	Marvel Cave									
TN	Bellamy Cave*	152,159			345,002	310,090	381,475		364,328	414,393
	Pearson Cave*	208,191			147,265	190,260	431,020		333,430	348,656
	Hubbards Cave*	513,079			346,286	238,365	283,480		397,116	500,253
	Tobaccoport Saltpeter Cave*		97	111	52	26	35		379	845
	Rattling Pit Cave								85,955	250,689
<b>Range-wide Population Estimate</b>									<b>4,504,520</b>	<b>5,306,905</b>

<sup>1</sup> Count was not completed at Mose Prater Cave in 2019; the 2017 survey estimate was used for 2019 so that a population estimate could be made for 2019.



**FIGURE 8.** The distribution of hibernating bats across states and major hibernacula. Distribution of bats chart is based on the 2019 hibernacula data (Table 8).

### 2.3.3 Genetics

Since the last 5-year review, we are aware of only one study evaluating the genetics of the gray bat. Lindsay et al. (2015) investigated whether there was genetic differentiation among eight large hibernacula, and if the Mississippi River Alluvial Plain created a level division that limits inter-population gene flow between hibernacula to the east and west of the plain. There are no major hibernacula and a very limited number of summer roosts within the Alluvial Plain. Sampling of bats occurred in 2005 and 2007, and Lindsay et al. (2015) considered 3 to 8 microsatellite loci per bat, as well as a 178-nucleotide-long locus of mitochondrial DNA. The authors found significant genetic differentiation among hibernacula overall. For the mitochondrial DNA, which is maternally linked and typically shows more genetic subdivision, hibernacula had significantly different genetic data, including significant differences between sites on either side of the Alluvial Plain.

In conjunction with significant genetic differentiation among individual hibernacula, 2 primary genetic populations were identified. Three of the sampled hibernacula (2 in Tennessee and 1 in Arkansas) were strongly aligned with 1 genetic population. This suggests inter-hibernacula genetic exchange from both sides of the Alluvial Plain. A hibernaculum in Kentucky was strongly associated with the second primary genetic population. The other 4 hibernacula showed less certain membership to a specific genetic group. Though the Alluvial Plain does not appear to be functioning as a complete barrier to gene flow, especially for populations in the north (Lindsay et al. 2015), the cluster assignment probabilities suggest a gene flow barrier between northern and southern hibernacula. We are unaware of a reason for this result as there are no physical features that would prevent movement between areas. The result is also not supported by band recoveries. Bands have been recovered from bats that have travelled between Kentucky and Tennessee (Mike Armstrong, pers. comm., 2021<sup>20</sup>) as well as Alabama and Tennessee (David Pelran, pers. comm, 2021<sup>21</sup>) and so movements of bats between southern and northern parts of the range in the east are known to occur, although the extent of these movements is unknown.

Lindsay et al. (2015) found no evidence of genetic bottlenecks among populations, with a bottleneck defined here as a population contraction. However, the test employed suggests that at least 10 loci must be used to achieve reasonable statistical power (Piry et al. 2017), and Lindsay et al. (2015) only used 8 or fewer loci. Therefore, it is unclear if the lack of detected bottlenecks is due to an actual lack of population contraction or a statistical artifact. Finally, the authors speculate there is a low likelihood of the species undergoing strong genetic drift, although strong genetic drift has been observed in *Myotis* species afflicted by white-nose syndrome (Auteri and Knowles 2020).

### 2.3.4 Taxonomic Classification

No changes to taxonomic classification or changes in nomenclature.

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<sup>20</sup> Mike Armstrong, USFWS biologist with the Kentucky Field Office, March 2021.

<sup>21</sup> David Pelran, USFWS biologist with the Tennessee Field Office, March 2021.

### 2.3.5 Spatial Distribution

The overall geographic range and distribution has changed relatively little since the gray bat was first listed as endangered in 1976. In particular, the number of occupied hibernacula has changed relatively little. Based on 2019 surveys, 98% of gray bats (5.3 million) occupy 15 hibernacula, and over 25% of these bats (approximately 1.3 million) occupy just 1 cave in Alabama (Figure 7). Given the small number of preferred occupied sites, gray bats are particularly vulnerable to impacts from natural and anthropogenic stressors.

Martin (2007) provided a range map in the 2007 “Assessment of Population Status of the Gray Bat (*Myotis grisescens*).” Since 2007, all sites documented in northwestern Florida have been abandoned (Gore et al. 2012) with maternity sites abandoned since at least the year 2000 (Lisa Smith, pers. comm., 2020<sup>22</sup>). Several thousand gray bats previously hibernated in Old Indian Cave in Florida (a Priority 1 hibernaculum) during the 1950s, but the number of bats dropped to fewer than 10 by 2002, and remained at fewer than 10 through 2011. Since 2011 and through 2019, the numbers have remained at zero (Gore et al. 2012, Lisa Smith, pers. comm., 2020<sup>23</sup>). The Priority 1 hibernaculum (Old Indian Cave) and the summer caves are considered protected, and the reason for the abandonment is unknown (Gore et al. 2012). Dugong Cave, the second and smaller of the 2 hibernacula in Florida, had a very small number of hibernating gray bats at any time. The recent declines are not considered related to white-nose syndrome, as the first cases of WNS were not observed until several years after populations of gray bats started to decline in Florida. Rises in temperature are also an unlikely factor since cave temperatures were recorded during some surveys and remain within the range used by gray bats in other places. Instead, it is more likely that gray bats moved to a larger and more suitable hibernaculum in northern Alabama. Florida represents the southern extent of the gray bat range, with all the caves occurring in northwestern Florida on the border with Alabama.

As discussed in Section 2.1.1, there appears to be a shift in the use of some hibernacula, with presumed movement of populations from one hibernaculum to another. For example, to a large degree, bats abandoned Tobaccoport Saltpeter Cave and completely discontinued using Old Indian Cave. However, there are now large numbers of bats in a previously less populated Rattling Pit Cave. The cause for the movements is unknown, but as gray bat populations recover and there are more individuals on the landscape, it is not surprising that bats may begin to reclaim historical caves or try to occupy new ones. The Missouri Field Office is occasionally informed of populations of gray bat maternity and bachelor colonies occupying caves that were previously vacant (no evidence of guano).

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<sup>22</sup> Lisa Smith, biologist with the Florida Fish and Wildlife Conservation Commission, August 12, 2020

### **Habitat or ecosystem conditions (e.g., amount, distribution, and suitability of the habitat or ecosystem):**

Our general understanding of habitat and ecosystem conditions has not significantly changed. However, see Section 2.2.1 for examples of recent gray bat use of artificial structures as roost locations. Gray bats have typically been considered year-round cave obligates, but over the last decade, there have been increasing reports of gray bat using artificial sites. Sasse (2019) documented a surprising frequency of gray bat use of bridges during the migration period.

## **2.4 Five-Factor Analysis**

Pursuant to the ESA and our implementing regulations, we must determine whether species are threatened or endangered based on any one or a combination of the following five section 4(a)(1) factors (i.e., the “five-factor analysis”): 1) the present or threatened destruction, modification, or curtailment of habitat or range; 2) overutilization for commercial, recreational, scientific, or educational purposes; 3) disease or predation; 4) inadequacy of existing regulatory mechanisms; and 5) any other natural or manmade factors affecting the species’ existence (16 U.S.C. 1533(a)(1), 50 CFR 424.11(c)). Below, we present our evaluation of the information regarding each of the ESA section 4(a)(1) factors and their impact on the extinction risk of the gray bat and whether any one or a combination of these factors are causing declines in the species or are likely to substantially negatively affect it within the foreseeable future to such a point that it is at risk of extinction now or likely to become so in the foreseeable future. Please refer to the 1982 Recovery Plan (USFWS 1982) and the 2009 5-Year Review (USFWS 2009) for additional in-depth information on the species’ biology and habitat, threats, and management efforts.

The 1976 final rule that listed the gray bat as endangered (41 FR 17736 17740; 4/28/1976) did not address the five-factor threats analysis later required by section 4 of the 1973 ESA. The Recovery Plan (USFWS 1982) identified threats or “causes of decline” as:

- Human disturbance to roosting bats. Recreational human entry into hibernacula and maternity colonies was considered the largest threat, with intent to kill bats also occurring on occasion.
- Roost modification and destruction (e.g., intentional cave entrance or mine sealing, modification of the internal environment and entrances, improper gating, cave commercialization)
- Natural calamities. Cave flooding, cave-ins, freezing, and disease are examples. Cave flooding is a particular concern, as gray bats retreat further back into caves and roost over water to avoid disruption from humans. Cave entrance closures due to cave-ins or gradual fill-in of sinkhole entrances may render an entrance and the cave no longer usable.

- Environmental contamination. Environmental contaminants (e.g. pesticides), siltation of waterways, deforestation near cave entrances along rivers and reservoirs where gray bats feed.
- Impoundment of waterways. Due to gray bat preference for caves near rivers, populations are particularly susceptible to inundation by man-made impoundments.

Additional potential threats that have been identified since the 1982 Recovery Plan include:

- Interactions with wind turbines
- White-nose syndrome
- Climate change induced changes to cave microclimates and cave flooding frequencies and intensity

The first two threats, human disturbance and roost modification and destruction have largely been addressed and are no longer adversely affecting the species to the degree or extent that they once did. As described in numerous sections, there has been a significant effort to reduce disturbance to maternity colonies and hibernacula through bat friendly gates and protection of caves where colonies roost. Survey data show that gray bat numbers have increased dramatically in locations where these threats were resolved. Natural calamities, environmental contamination, and impoundment of waterways may still be affecting the species to varying degrees, and in some cases the magnitude of impacts is unknown due to lack or limited number of studies (e.g., pesticide and other chemical contamination, siltation of waterways, reductions of available aquatic food resources). Lastly, some of the identified potential threats may only be realized in the future (e.g., interactions with wind turbines, climate change induced changes to cave microclimates). Although we discuss all relevant threats, we focus much of our discussion below on threats identified since the Recovery Plan: white-nose syndrome, interactions with turbines at wind energy facilities, and climate change.

#### **2.4.1 Present or threatened destruction, modification or curtailment of its habitat or range:**

As described above, most hibernacula and many of the large summer colonies across the range have a high degree of protection. While these caves are protected from human intrusion, natural calamities, such as collapse within the cave or at the entrance, cannot be foreseen or prevented. For example, a rock fall blocked the entrance of Bonanza Cave in Arkansas around 1997. The cave entrance is in a bowl at the bottom of a bluff and additional rockfalls could trap bats inside the cave though a current cupola gate might mitigate this risk to some extent (Sasse, pers. comm., 2021<sup>24</sup>).

Given that approximately 98% of gray bats roost in as few as 15 major hibernacula, natural calamities at just one hibernaculum could result in the loss of a significant amount

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<sup>24</sup> Blake Sasse, biologist with the Arkansas Game and Fish Commission. February 2021.

of roosting habitat or bats. Natural calamities such as a collapse of rock at the entrance or within the cave could close off access to one or more roosting sections of the cave, or affect air flow, temperature and humidity throughout the cave, making it unsuitable for use. For instance, a collapse blocking major flyways into and out of Fern Cave, which supports an estimated 1.3 million hibernating bats in the winter, could displace or kill as much as 25% of the gray bat population if bats were trapped inside. Therefore, natural calamities could represent a threat to gray bats, but the likelihood of such events is impossible to predict or estimate. Given the lack of cave-ins since the Recovery Plan was published and few records for cave-ins in general, we consider the threats to be infrequent and therefore unlikely, but potentially substantial if they were to occur at any of the major hibernacula.

#### **2.4.2 Overutilization for commercial, recreational, scientific, or educational purposes:**

Human disturbance to summer roosting and hibernating bats was originally identified as one of the primary threats to the species. The primary forms included recreational caving, cave commercialization (i.e., cave tours and other commercial uses of caves) and vandalism. Cave commercialization and vandalism are no longer considered to be major threats, although these forms of disturbance do occur on occasion. For example, several hundred gray bats were killed with a shotgun at a summer roost in Arkansas (Sasse, pers. comm., 2021). Recreational caving may impact smaller hibernacula, summer colonies, and transient caves that are not monitored or protected and where access is not restricted. However, disturbance of gray bats seldom results in immediate mortality of bats within the roost, except in cases of vandalism when bats are purposely killed.

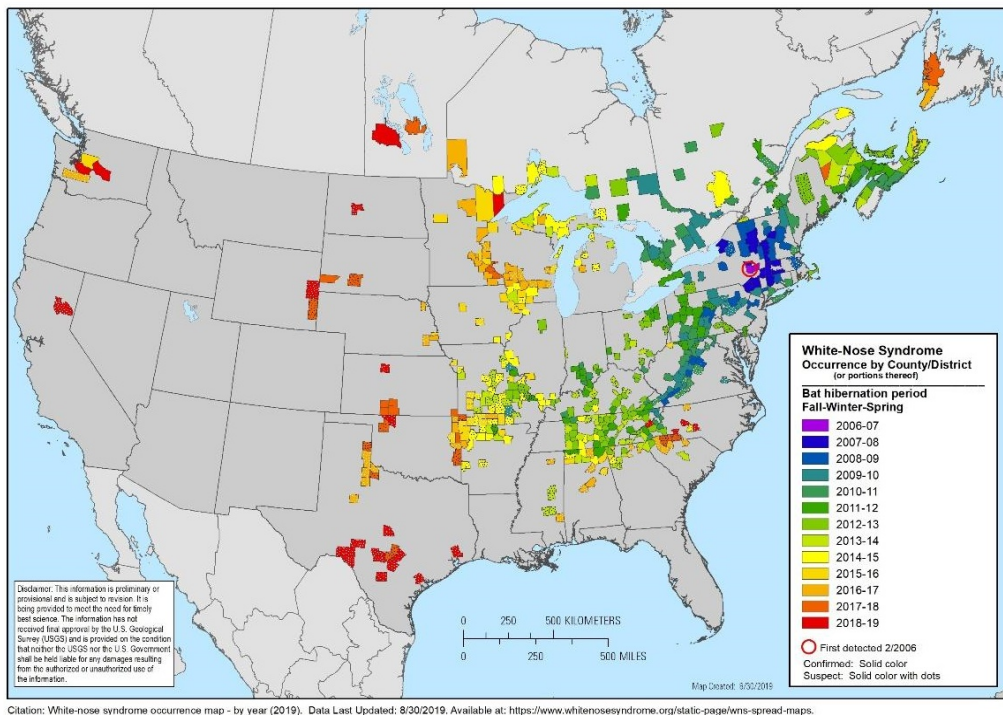
Although impacts from human disturbance have not been completely eliminated, significant progress has been made to reduce human disturbance (see Section 2.1.1 and Section 2.1.3 for a discussion on which sites are protected). More than 90% of major hibernacula, which are estimated to support approximately 98% of hibernating gray bats are owned by a conservation focused organization and have restricted access. More than half of Biologically Significant maternity and large bachelor colonies have also been protected: 32 of 46 Category 1 and 21 of 49 Category 2, or a combined total of 53 of 95 (56%) summer roosts.

#### **2.4.3 Disease or Predation: White-Nose Syndrome**

White-nose syndrome was listed as an emerging threat to gray bats in the species' 2009 5-year review. At that time, the spread of WNS was believed to pose a catastrophic threat to the species and was expected to result in the immediate reversal of recovery achieved up to that point. However, information gathered since 2009 shows the gray bat population is stable despite the introduction of WNS throughout its range (Janicki et al. 2015) and that the species is potentially resistant to the disease (Frick et al. 2017).

White-nose syndrome is an infectious disease caused by the psychrophilic fungus *Pseudogymnoascus destructans* (*Pd*). It grows optimally between 12-15° Celsius (53.6 to

59° Fahrenheit) (Verant et al. 2012), but can remain viable at higher temperatures outside of its growth range (Campbell et al. 2020). This fungus infects cave-dependent bats upon their return to hibernacula (Langwig et al. 2015) and may result in disease if homeostasis is disrupted following the invasion of fungal hyphae in bats' skin during hibernation (Bernard et al. 2017a, Warnecke et al., 2012, Meteyer et al., 2009). White-nose syndrome threatens several cave-dependent bat species throughout the country and is considered one of the worst wildlife diseases of modern times (WNS 2019). Since its emergence in the United States in New York in the winter of 2006-2007, *Pd* has spread to 35 States and 7 Canadian Provinces (Figure 9; WNS 2019); and millions of bats have died from the subsequent syndrome.



**FIGURE 9.** White-nose syndrome occurrence by county/district and year from 2006 to August 2019. Map copied from <https://www.whitenosesyndrome.org/>.

White-nose syndrome has been confirmed in 12 North American bat species, including gray bats (WNS 2019), and both the fungus and the associated disease have been found in hibernacula used by gray bats. The fungus has also been detected on gray bats from wing and muzzle swabs during hibernation (Bernard et al. 2017a, Spadgenske 2013). Bats exhibiting white fungal growth around the muzzle were also noted during surveys by Cory Holliday (Holliday, pers. comm., 2021). However, the only confirmed cases of the disease in the species come from 2 individuals (USFWS 2012), likely as a result of few individuals found dead and tested for verification of the disease. WNS was not confirmed in the species by the U.S. Geological Survey's National Wildlife Health Center, which processed 71 gray bats from 8 states between February 2009 and April 2019 (Ballmann,

pers. comm., 2020<sup>25</sup>). Generally, state agencies do not report seeing typical presentations of white-nose syndrome on hibernating gray bats during routine winter surveys.

Fungal loads and prevalence appear to be low in gray bat populations as well (Bernard, et al. 2017a, Frick et al. 2017), with infections nearly always cryptic (Janicki et al. 2016). These findings indicate both a low rate of transmission and infection load, the opposite of that associated with highly susceptible species with high mortality rates (Frick, pers. comm., 2020<sup>26</sup>), as well as resistance to the disease (Frick et al. 2017). It should be noted, however, that gray bats exhibit wing damage similar to that associated with WNS (Photo 1), and some individuals surveyed with visible membrane damage also tested positive for *Pd* (Spadgenskie 2013, Keel, pers. comm., 2012<sup>27</sup>). Nonetheless, substantial wing damage and discoloration in the species was recorded prior to the introduction of *Pd* (Armstrong, pers. comm., 2020<sup>28</sup>; Bernard et al. 2017a, Lamb, pers. comm., 2020<sup>29</sup>, and Sasse, pers. comm., 2020<sup>30</sup>), and so wing damage is known to result from sources other than WNS. In addition, similar findings documented after the introduction of the fungus have been found to be unrelated to WNS (Kevin Keel, pers. comm., 2012.) based on ultraviolet and polymerase chain reaction (PCR) results (Bernard et al. 2017a).

**PHOTO 1.** Significant non-WNS wing damage on a gray bat noted during an April 2019 survey. Photo credit: Dr. Joy O’Keefe, University of Illinois.



The mechanisms of the gray bat’s potential resistance to WNS are not well understood, and research on this topic is ongoing. Potential explanations include the following:

1. Body Size: One potential explanation is that as a larger-bodied *Myotis* bat species, gray bats are better able to store and maintain greater amounts of fat with a lower

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<sup>25</sup> Anne Ballman, wildlife disease specialist with the USGS National Wildlife Center, July 27, 2020

<sup>26</sup> Winifred Frick, chief scientist with Bat Conservation International, July 16, 2020

<sup>27</sup> Kevin Keel, associate professor with the University of California (UC Davis), March 30, 2012.

<sup>28</sup> Michael Armstrong, wildlife biologist with the U.S. Fish and Wildlife Service, November 6, 2020

<sup>29</sup> John W. Lamb, biologist with Arnold Air Force Base, August 5, 2020

<sup>30</sup> Blake Sasse, non-game mammal biologist with the Arkansas Game and Fish Commission, August 2, 2020

surface-to-volume ratio. This reduces the area available for infection and decreases evaporative water loss seen in smaller species such as *M. lucifugus* (Frank et al. 2014, Geiser et al. 2011, Willis et al. 2011).

2. Microclimate Preference: Another potential reason for resistance could be attributed to microclimate preferences. It has been suggested that gray bats prefer colder, drier microclimates during hibernation that are not optimal for *Pd* growth (Bernard et al. 2017a, Bernard et al. 2017b, Elliott 2007). Colder and dryer microclimates are associated with increased evaporative water loss, which has been attributed with WNS-related mortality. However, gray bat clustering behaviors may decrease evaporative water loss (Willis et al. 2011) thereby enabling the species to take advantage of *Pd*-prohibitive environments without increased risk of dehydration and subsequent mortality. However, in places like Missouri, where gray bats tend to select caves that have more humidity and warmer temperatures that present optimal conditions for *Pd* growth, gray bats still appear to have no incidence of WNS-related mortality.
3. Torpor Bout Length: Bats tend to experience longer torpor bouts at lower temperatures (Twente et al. 1985). Extended bouts are generally thought to increase the risk of infection due to reduced immune responses during torpor (Meteyer et al. 2009). However, gray bats are known to be more active than other species in the winter (Parris 2013), with activity levels correlated to temperature, not disease, and consistent with pre-WNS levels (Bernard et al. 2017b). Though this increased activity is energetically expensive, gray bats are thought to utilize winter feeding (Parris 2013), and such episodic feeding is believed to increase immunological defenses while also counteracting negative energy expenditures (Bernard et al. 2017a). Additionally, it is possible that gray bats also engage in grooming behaviors during this time, further reducing their risk to WNS.
4. Hibernation Duration: Gray bats are believed to enter hibernation later and emerge earlier in the spring than other species, thus reducing their hibernation periods to less than 4 months and potentially protecting them from mass mortality events experienced by more susceptible species (Bernard et al. 2017b). Cutaneous lesions are the only consistent pathological association with WNS, and in experimental inoculation trials with little brown bats (*Myotis lucifugus*), lesions were not apparent until 83 days post-inoculation. Mortality did not occur until approximately 120 days (approximately 4 months) after bats entered hibernation, with peak mortality after 180 days (Lorch, et al. 2011, Hoyt et al. 2015). Because of the shorter hibernation period for many gray bats, they may be less prone to impacts of WNS that lead to mortality.
5. Microbiome: It is also hypothesized that gray bats may have an innate resistance to the fungus associated with its skin microbiome structure. Antifungal bacteria have been collected from gray bats' skin, and shown to inhibit the growth of *Pd*.

Several species of bacteria from the genus *Pseudomonas* have been shown to have these inhibitory properties, the strongest of which were cultured from *Eptesicus fuscus* (Hoyt et al. 2015), a species thought to be resistant to WNS (Frank et al. 2014). Additionally, research indicates 3 distinct structures of microbiomes among a wide variety of species, with similar skin microbiome diversity found on both *E. fuscus* and gray bats, indicating likely resistance (Campbell, pers. comm., 2020<sup>31</sup>). Whether these distinctions are independent of other variables or interdependent upon microclimates has yet to be determined, but strong evidence indicates a link between microbiome species and the survival of *Pd* (Campbell, pers. comm., 2020<sup>1</sup>).

In short, although the extent of potential non-lethal impacts (such as possible reductions in fitness or reproductive success) from WNS remains unknown, mass mortality events associated with WNS have not been recorded for gray bats (Bernard et al. 2017b). The Missouri Field Office is currently investigating how climate change induced changes to cave microclimates may impact hibernating bats and in turn their susceptibility to white-nose syndrome.

#### **2.4.4 Inadequacy of existing regulatory mechanisms:**

Ownership of gray bat habitat is likely the primary factor that limits effectiveness of existing regulatory mechanisms. ESA protection extends to hibernacula that are privately owned, but recovery options are often limited on private lands. If gray bats were to be delisted from the ESA, populations on private properties would not be afforded federal protections. However, it should be noted that many private hibernacula owners are cooperative in efforts to protect gray bats. Because many landowners are cooperative in efforts to protect gray bats, and the majority of properties containing major gray bat hibernacula have already been purchased, the threat is primarily to maternal, bachelor, and migratory sites. More than half of the largest maternity colonies have been protected (56%).

#### **2.4.5 Other natural or man-made factors affecting its continued existence:**

Anthropogenic factors that may affect gray bats include:

1. Human disturbance
2. Roost modification
3. Environmental contaminants
4. Impoundments of waterways
5. Collisions with wind turbines
6. Climate change

As previously stated, the first two factors, human disturbance and roost modification and

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<sup>31</sup> Lewis Campbell, National Wildlife Health Center, July 17, 2020

destruction have largely been addressed and are no longer adversely affecting the species to the degree or extent that they once did. As described in numerous sections, there has been a significant effort to reduce disturbance to maternity colonies and hibernacula through bat friendly gates and protection of caves where colonies roost. Improper gating is also no longer a significant threat to gray bats. With time and experience, the cave gating community learned valuable lessons on what gates work best for gray bats. Current designs include bat-friendly fly-over and chute style gates that provide gravid females with ample flight space in and out of roosts. There is also currently more attention given to the potential impacts of gates on cave airflow dynamics. Cave gate designers are aware that the gate should ensure the structure does not prevent or appreciably reduce airflow in and out of the cave entrance(s) and disturb cave microclimates necessary for hibernation. Survey data show that gray bat numbers have increased dramatically in locations where these threats were resolved.

Environmental contamination and impoundment of waterways may still be affecting the species to varying degrees. The level on impact from environmental contamination on gray bats is difficult to assess due to the lack or limited number of studies (e.g., pesticide and other chemical contamination, siltation of waterways, reductions of available aquatic food resources). The number and placement of future water impoundment projects are unknown and thus the magnitude of this particular threat is also very difficult to assess.

For this review, we have focused on two emerging anthropogenic threats: wind energy/turbines and climate change.

#### **2.4.5.1 Wind Energy**

Present wind energy distribution overlaps with only a small portion of the gray bat's range, and wind-generating capacity is relatively low in the southeastern U.S. (Figure 10; Hoen et al. 2018). Two wind facilities are currently operating within the range of gray bat, however at present neither have reported impacts to gray bats.

The Buffalo Mountain Wind Facility (operating at current capacity, 18 turbines, 29 megawatts (MW) since 2004) in Tennessee is one of two operating facilities in the range of the gray bat. The facility is 16 miles from a colony of approximately 5,000 gray bats. No gray bat fatalities were detected during post-construction fatality monitoring of the first 3 turbines (2 MW) that occurred from September 2000-September 2003. Further, no gray bats were documented during post-construction fatality monitoring when an additional 15 turbines, (27 MW) were erected and monitored from April-December 2005 (Fiedler 2004, Fiedler et al. 2007, Nicholson et al. 2005).

North Fork Ridge and Kings Point wind facilities (Barton, Dade, Jasper, and Lawrence counties, Missouri) are the only other wind facilities operating in the range of the gray bat. Empire District Electric Company has initiated an Activity-Based Informed Curtailment study at these facilities to assess the impacts of wind power on gray bats with the goal of identifying an effective and optimal curtailment strategy. Several other wind facilities are currently scoping within Missouri (as of October 2021).

According to 2020 data compiled by the American Wind Energy Association approximately 24,445 MW are currently installed in the twelve states that make up the gray bat range (see Figure 10). An additional 9,293.1 MW are currently under advanced development; however, the location of most of this development is not available. Of the existing capacity and capacity under advanced development, only 327.9 MW (including one facility in TN, and two in MO) are known to be within the gray bat range.

Because so few wind energy facilities exist within the range of the gray bat, and because the largest wind facility within the range operates specifically to avoid take, wind power does not currently have a meaningful impact on gray bats; however, capacity is continuing to expand in the Midwest and Southeast, and future build-out is likely to contribute new impacts to the species. To understand the potential expansion of wind energy into gray bat range we 1) evaluated wind energy development under two future scenarios, 2) determined an average all-bat fatality rate using post construction monitoring data at wind facilities in the Service’s Midwest Region, 3) identified little brown bat as an analogous species to estimate future wind impacts to gray bats, 4) report estimated impacts to gray bats under the two build-out scenarios, and 5) discuss estimated gray bat fatalities in relation to information on current population status.

## 1. Projected Wind Energy Development

We determined an *adjusted baseline capacity within the gray bat range* (1,943.84 MW, cumulatively) by aggregating the capacity of currently installed capacity within the gray bat range, capacity under advanced development within the gray bat range, and the capacity under advanced development where locations are unknown<sup>32,33</sup>. We then evaluated wind development under two scenarios; Scenario 1: U.S. Energy Administration (USEIA) Estimated Average Annual Growth, and Scenario 2: Wind Vision Scenario, using Department of Energy’s (DOE) Wind Vision Report to project development such that wind power supplies 20% of national electricity demand by 2030 and 35% by 2050 (Figure 11, DOE 2015).

### *Scenario 1: USEIA Estimated Average Annual Growth*

The U.S. Energy Information Administration’s energy forecasts predict an average nationwide growth rate of 1.8% annually for installed land-based wind energy capacity between 2019 and 2050 (USEIA 2020). The DOE report categorizes USEIA’s Energy Outlook as a “business as usual scenario” because the USEIA Energy Outlook models

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<sup>32</sup> Where the location of wind capacity under advanced development is unknown, we factored in the proportion of each state that falls within the gray bat range (Figure 1) and assumed that future wind development is equally likely to occur throughout a given State. For example, approximately 40% of Arkansas falls within the gray bat range, and 180 MW are under advanced development (AWEA 2020). Therefore, the adjusted baseline capacity within gray bat range for Arkansas is 72.0 MW (0.40 x 180).

<sup>33</sup> For States within gray bat range where wind capacity is not under development, we assigned a hypothetical baseline capacity of 29 MW (using existing capacity in TN, the smallest wind energy contributing State in gray bat range, as a placeholder) to estimate future wind development in Scenario 1 (explained above).

wind deployment under current policy conditions, and not considering the increasing demand for renewable energy. For example, the Biden administration announced in April 2021 that the U.S. will aim to cut carbon emissions by as much as 52% by 2030, which, if realized, will inevitably result in more land-based wind development (The White House 2021). Thus, this forecast likely represents the lower boundary of wind development, totaling approximately 187 gigawatt (GW) of land-based wind in the US by 2050 (USEIA 2020). We projected future wind development in the gray bat range by applying the average growth rate per state to the *adjusted baseline capacity within the gray bat range* for the next 30 years (to year 2050). As a result, we estimate a total capacity of 2,323.48 MW (2.3 GW) within the gray bat range by the end of year 2030, and a total capacity of 3,319.66 MW (3.3 GW) in the gray bat range by the end of year 2050.

#### *Scenario 2: DOE Wind-Vision*

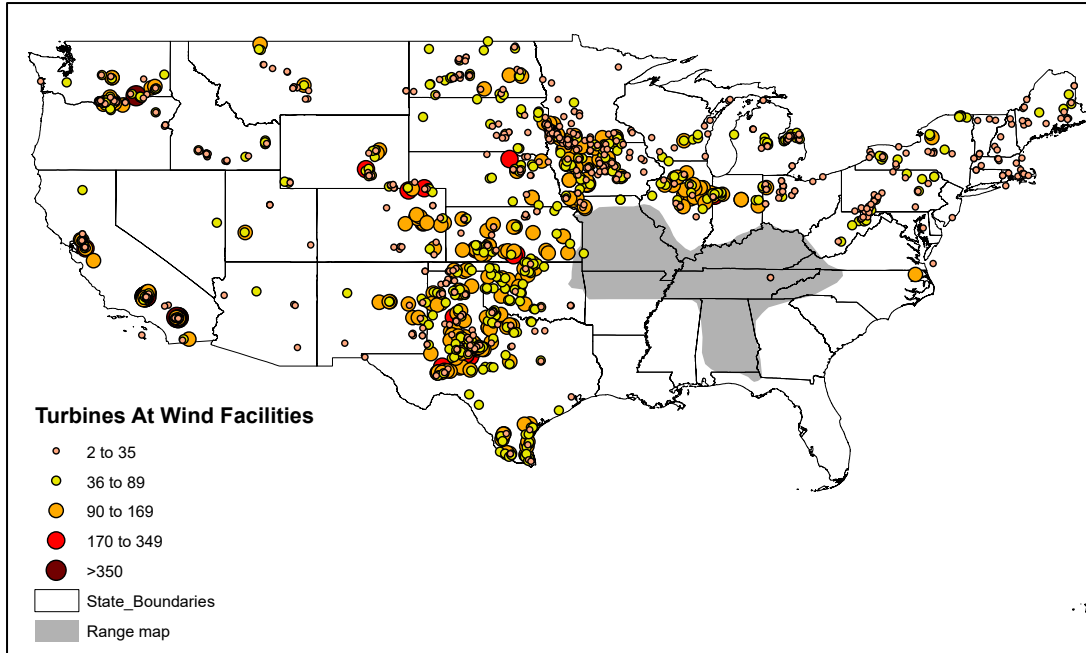
The DOE 2015 wind vision report develops and analyzes an ambitious wind development scenario, such that total wind energy (land-based and offshore, cumulatively) provides 10% (113 GW) of the nation's energy demand by 2020, 20% (224 GW) by 2030, and 35% (404 GW) by 2050. The scenario is ambitious yet credible and was developed through a series of scenario modeling that supports analyses of potential costs, benefits, and impacts associated with future wind development. For comparison with what has actually occurred, at the end of 2020 approximately 122 GW of total wind energy capacity was operating in the United States (ACP 2020). At present, nearly all wind energy capacity is land-based, however the wind vision report envisions offshore wind to compose approximately 10% of total wind energy capacity by 2030, and approximately 20% by 2050. The Wind Vision Report envisions 318 GW of land-based energy by 2050, 131 more GW than estimated by USEIA (USEIA 2020 estimates 187 GW of land-based wind capacity by 2050).

We only included land-based wind energy estimates when developing build-out scenarios into gray bat range. Under Scenario 2 we estimate a total capacity<sup>34</sup> of 12,339.5 MW (12.3 GW) within the gray bat range by the end of year 2030, and a total capacity of 22,586.5 MW (22.6 GW) in the gray bat range at the end of year 2050.

To put Scenarios 1 and 2 into context, the current installed capacity is 26,354 MW within the Service's Midwest Region. The geographic distribution for this expanded wind potential would include new regions, such as the southeastern U.S. (DOE 2020). As wind capacity increases within the southeastern U.S., a substantially larger portion of the gray bat's range could be exposed to wind turbines (Figure 11). To estimate potential impacts of future wind facilities on gray bats, we reviewed available data of bat fatalities at wind energy facilities, and assumed a gray bat fatality composition using the little brown bat as an analogous species, as explained below.

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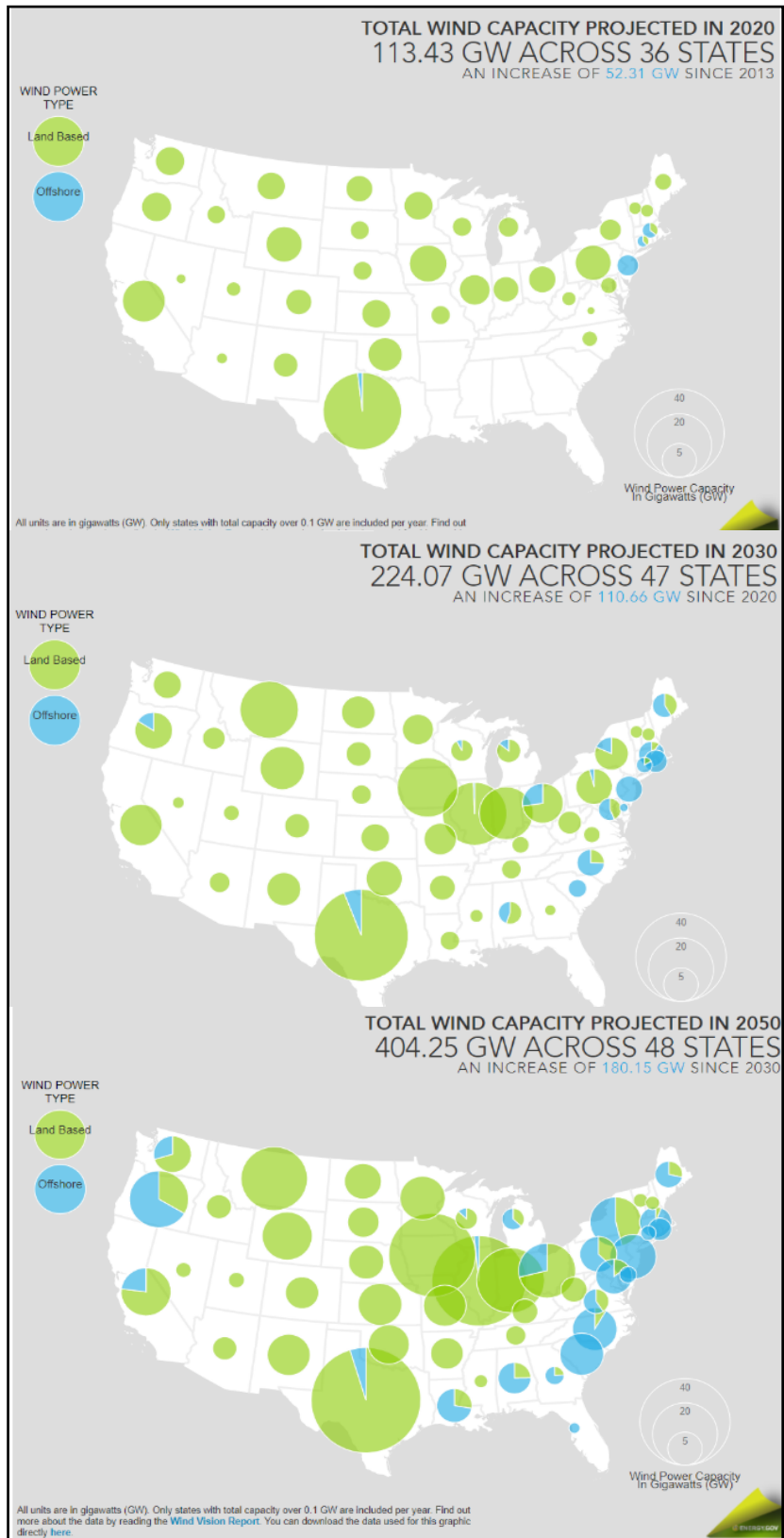
<sup>34</sup> The DOE 2015 wind vision report estimates the wind development in each State that would contribute to meeting the 2030 and 2050 wind development scenarios. Following the same procedure as in Scenario 1, we estimated the buildout into gray bat range by factoring in the proportion of each state that falls within gray bat range (Figure 1) and assumed that future wind development is equally likely to occur throughout a given State. To determine annual projections, we interpolated an annual average growth rate between the 2030 and 2050 projections for each State that makes up the gray bat range.



**FIGURE 10.** Distribution of wind turbines included in the United States Wind Turbine Database<sup>35</sup> (Hoen et al. 2018) as of April 2020. Larger circles represent facilities with a greater number of turbines; gray shading represents the gray bat range. Facilities with 1 turbine are not depicted.

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<sup>35</sup> The database includes turbine data from the Federal Aviation Administration's (FAA) Digital Obstacle File (DOF) and Obstruction Evaluation Airport Airspace Analysis (OE-AAA), the American Wind Energy Association (AWEA), Lawrence Berkeley National Laboratory (LBNL), and the United States Geological Survey (USGS).



**FIGURE 11.** Total wind capacity projected in 2020, 2030, and 2050. Figures is from the Department of Energy (2015). Only States with total capacity over 0.1 GW are included.

## 2. Bat Fatalities at Wind Facilities

Interactions with wind turbines are a well-documented source of fatality for bats. Large-scale fatalities of some bat species have been demonstrated at multiple wind energy facilities, and recent studies have found that far more bats than birds are typically killed in the Midwest and eastern United States (Arnett and Baerwald 2013, O’Shea et al. 2016). Based on the number and frequency of documented deaths of bat species observed at wind energy facilities throughout North America, there appears to be little to no avoidance of wind facilities by bats (USFWS 2011). Due to lack of avoidance, we do not expect bats to be displaced from areas with new wind facilities; instead, we focus our analyses on the potential impact of turbine collisions to gray bats.

Numerous studies have focused on evaluating impacts to bats from wind facilities. One hypothesized reason that bats come near wind turbines is due to random collision (Cryan and Barclay 2009). However, growing evidence indicates that some species of bats are attracted to wind energy facilities or wind turbines (Horn et al. 2008, Cryan et al. 2014). Thermal imaging studies reveal that bats approach rotating and non-rotating blades, investigating various parts of the turbine with some individuals even attempting to land on the blades and towers, thereby colliding with the turbine blades (Horn et al. 2008; Cryan et al. 2014). Although data suggest that certain species of bats are attracted to wind turbines, it is still unclear what the factor(s) of attraction might be (Hein and Schirmacher 2016).

To understand the impact future wind energy build-out could have on gray bats, we reviewed Service data from compiled post-construction monitoring at wind facilities within the Service’s Midwest Region (USFWS 2020 unpublished data)<sup>36</sup> and derived a baseline all-bat fatality rate. The Service compiled data from studies where turbines did not use cut-in speeds (i.e., the wind speed at which turbines “cut-in” to the wind and begin producing power), and further filtered studies that included a minimum weekly search interval. These compiled data were adjusted for seasonal distributions in fatality, survey period, and area of plot searched. We further filtered available studies to only include data prior to white-nose syndrome disease arrival in each State. As WNS-affected bat populations decline it appears that fatality rates at wind facilities also decline. Gray bats do not appear to be affected by WNS, so it is important to consider pre-WNS fatality rates in estimating impacts to the species. We used data from the Midwest Region because the geographic scale is comparable to the range of the gray bat. In other words, the spatial distribution of post-construction studies is comparable to the geographic range of the gray bat, as opposed to isolated studies within a more localized area, although not within gray bat range. Post construction monitoring data from wind facilities across the region were available for compilation and standardization, and studies included data from

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<sup>36</sup> We also reviewed and considered AWWI’s USFWS Region 3 and 5 reported fatality and composition data, and considered the finer-scale reporting based on ecoregions (AWWI 2018). However, the report only provides median fatality rates, and doesn’t specify fatality rates for each EPA Level III Ecoregion. We ultimately decided not to include an analysis using statistics reported in AWWI 2018 due to the limited information provided and to maintain consistency in geographic scale (e.g., Ecoregion vs. Service Region).

pre-WNS time periods. As a result, 38 studies were used to derive a baseline average all-bat fatality rate of 14.2 bats/MW/year (b/MW/yr).

### 3. Little Brown Bat as an Analogous Species

Because there are too few wind facilities in the range of gray bats currently operating, we used an analogous species approach to evaluate the future risk to gray bats posed by the expected expansion of wind facilities into the species' range. In considering potential analogous species we assessed the life history characteristics of 19 bat species with documented impacts from wind facilities.

Little brown bat was selected as the most comparable analog because, like gray bats, they are strong fliers that migrate between summer and winter grounds, forage near and over water bodies, and hibernate in caves in large numbers. We considered cave myotis (*Myotis velifer*) as another potential analog to which the gray bat could be compared; however, limited data precluded selection as a species because too few wind facilities within the range of the species reported any fatality data. Both gray bats and little brown bats are often documented hunting in open conditions, typically over and adjacent to large waterbodies (Moore et al. 2017; Nelson and Gillam 2017). Both little brown and gray bats are considered among the most open-air hunting species of the *Myotis* genus (Chris Corben, pers. comm, 2020<sup>37</sup>). Both species are relatively powerful flyers; gray bat wing loads<sup>38</sup> are similar to that of the little brown bat (gray bat: 8.0 g/m<sup>2</sup>; little brown bat: 7.5 g/m<sup>2</sup>). Although not to the magnitude of gray and cave myotis summer roosts, little brown bats also form large nurseries during the summer, which can consist of several hundred individuals (Olsen and Barclay 2013). In the winter, little brown bats congregate by the thousands in hibernacula, although this is increasingly rare as a result of reductions in populations due to white-nose syndrome. Little brown bat seasonal movements are likely comparable in length to that of gray bat. Norquay et al. (2013) determined that the little brown bat had a 463 km (288 mile) median distance between summer roosts and hibernacula; gray bat band recoveries indicate that bats can have very short migration distances <100 miles but have been recorded to move as far as 497 miles (Elder and Gunier 1976). Holliday<sup>39</sup> generally estimated that bats for which information is available in Tennessee appear to migrate approximately 200 miles on average.

Although the species are similar, it is possible that gray bats may be more vulnerable to wind turbine collisions than little brown bats if those turbines are located near roosts or between roosts and foraging locations, because gray bats congregate in larger numbers during the spring, summer and fall, and may travel over longer distances to foraging grounds within their summer home range. However, because of the species similarities and the lack of gray bat specific fatality data (due to the current limited overlap of wind facilities with gray bat range), we assume the impacts of wind turbines to the little brown

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<sup>37</sup> Chris Corben, biologist with Titley Scientific. Personal communication on December 19, 2020.

<sup>38</sup> A wing load is the mass of an animal divided by the area of its wing. Wing loads were assessed by Farney and Fleharty in the 1969 publication titled "Aspect Ratio, Loading, Wing Span, and Membrane Areas of Bats" (Farney and Fleharty 1969)

<sup>39</sup> Cory Holliday, the Nature Conservancy. Personal communication, February 23, 2021.

bat (prior to WNS) are comparable to what we could observe for gray bats. Therefore, we used the reported little brown bat composition of wind fatalities from within the Service’s Midwest Region (USFWS 2020 unpublished data; 11.13% of the all-bat fatality rate, pre-WNS) to estimate potential fatalities of gray bats, under projected wind build-out scenarios below.

#### 4. Estimated Gray Bat Fatalities

As explained above, we derived a baseline average all-bat fatality rate (14.2 b/MW/yr) and species composition for little brown bats (11.13%) and determined little brown bats to be a reasonable analog for which to estimate impacts to gray bats. Regarding future wind expansion, we assume facilities will operate as recommended in American Wind Energy Association (AWEA) 2015 guidelines (feather<sup>40</sup> turbine blades such that rpms are minimal when wind speeds are below manufacturers’ rated cut-in speeds [approximately 3.5 m/s<sup>41</sup>]), which are expected to reduce all bat fatalities by 30%. Therefore, projected wind facilities are anticipated to have an average all bat fatality rate of 9.94 b/MW/yr and an anticipated gray bat fatality rate of 1.11 b/MW/yr (Table 10).

The manner in which future wind facilities will operate is uncertain. Facilities that risk the take of listed bats may pursue an ITP, and avoid, minimize, and mitigate impacts to listed bats (therefore reducing impacts by much more than 30%). Other facilities may determine that their expected impact is very low and could choose to operate without minimizing impacts. The AWEA conservation guidelines are recommended by wind industry and the Service as a way to minimize impacts to all bat species (not specifically to avoid or minimize for the purposes of ESA), and we have determined this is a reasonable scenario in which to estimate future impacts to gray bats especially given other listed bats (e.g. Indiana bat (*M. sodalis*) and northern long-eared bat (*M. septentrionalis*)) overlap the majority of the gray bat range.

**TABLE 10.** Estimated gray bat fatality rate at wind facilities estimated using little brown bats as an analogous species and compiled all-bat fatality rates from USFWS 2020.

Little brown bat composition	Mean all bat fatality rate (b/MW/yr)	Gray bat fatality rate (bats/MW/yr)
11.13%	9.94	1.11

Applying the gray bat fatality rate to wind build-out scenarios in the gray bat range yields the estimated range-wide fatalities in Tables 11 and 12. Because the fatalities from projected wind facilities increase annually out to 2050, we reported the average annual wind fatalities over the time frame of this analysis. Projected annual fatalities by State, for each scenario are reported in Figures 12 and 13.

<sup>40</sup> Feathering is reducing the blade angle to the wind to slow or stop the turbine from spinning. Cut-in speeds are the wind speed at which rotors begin rotating and producing power. Below the cut-in speed, turbine blades can be “feathered” so that they do not spin until a designated cut-in speed is reached.

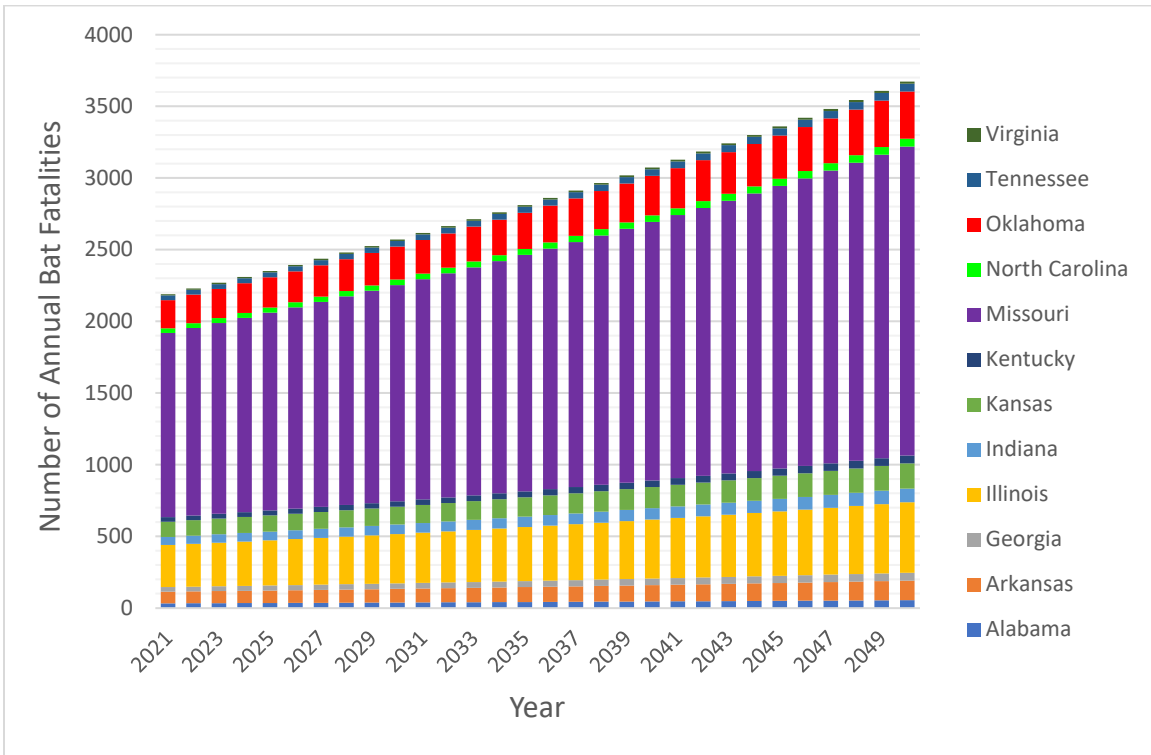
<sup>41</sup> For comparison, most wind facilities in the Service’s Midwest Region who are authorized take through an ITP operate at cut-in speeds of 5.0 m/s during times of the year when risk of take is greatest. Wind facilities that adjust operations to avoid take (for example, while pursuing an ITP) may operate at higher cut-in speeds ranging from 6.9-8.0 m/s.

**TABLE 11.** Scenario 1: Estimated wind capacity within gray bat range and aggregated range-wide fatalities in years 2030 and 2050.

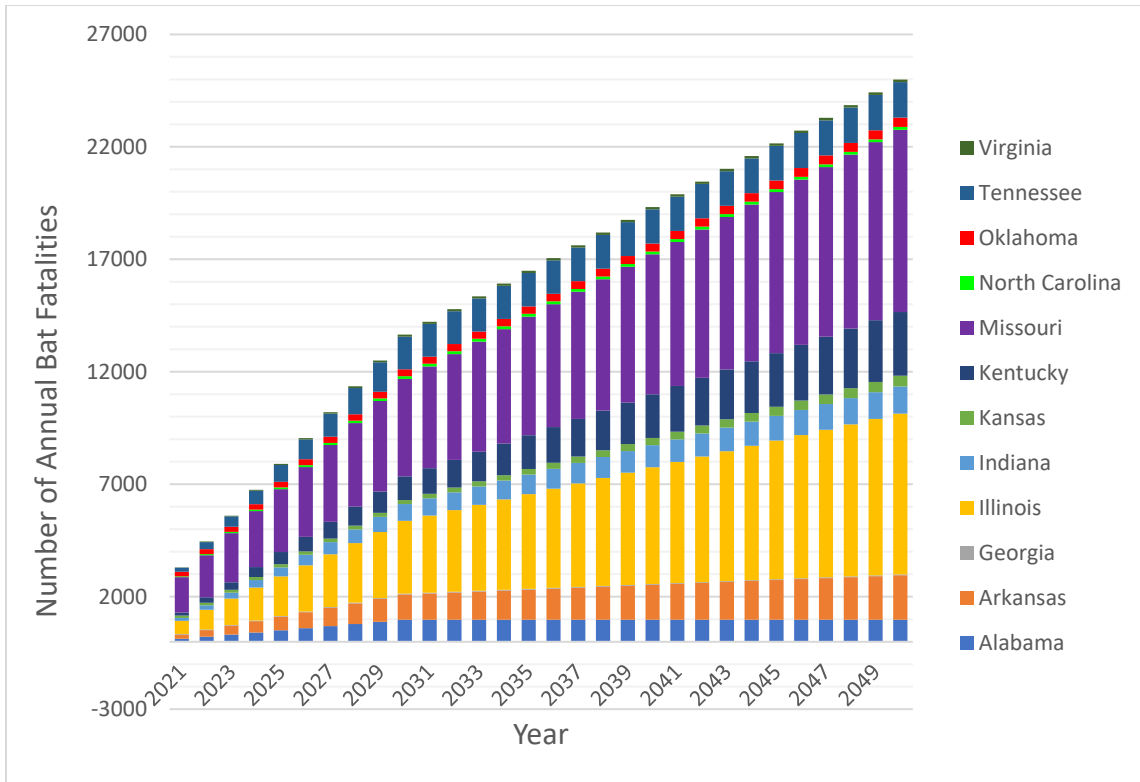
Projected wind capacity by 2030 (MW)	Projected wind capacity by 2050 (MW)	Range-wide gray bat fatalities in year 2030	Range-wide gray bat fatalities in year 2050	Average range-wide annual gray bat wind fatalities 2020-2050
2,323.48	3,319.66	2,570.51	3,672.61	2,869.44

**TABLE 12.** Scenario 2: Estimated wind capacity within gray bat range and aggregated range-wide fatalities in years 2030 and 2050.

Projected wind capacity by 2030 (MW)	Projected wind capacity by 2050 (MW)	Range-wide gray bat fatalities in year 2030	Range-wide gray bat fatalities in year 2050	Average range-wide annual gray bat wind fatalities 2020-2050
12,339.50	22,586.50	13,651.46	24,987.94	15,894.09



**Figure 12.** Projected annual gray bat fatalities based on estimated wind build-out for each state within the range of the gray bat under Scenario 1. Number of bat fatalities for each year’s bar is presented in the order they appear in the Legend (Virginia is at the top and Alabama is at the bottom).



**Figure 13.** Projected annual gray bat fatalities based on estimated wind build-out for each state within the gray bat range from 2021 to 2049 under Scenario 2. Number of bat fatalities for each year’s bar is presented in the order they appear in the Legend (Virginia is at the top, and Alabama is on the bottom).

## 5. Discussion

### *Projected Wind Energy Development*

Under Scenario 1 (projections using EIA average growth rate) approximately 3,319.66 MW could be installed within gray bat range by the end of 2050. The actual growth rate in wind energy development could be greater than the projected rate as demand for renewable energy increases and wind development technology advances. Therefore, Scenario 1 could underestimate wind development into the gray bat range. Under Scenario 2 (projections using DOE wind vision) approximately 15,894.09 MW could be installed within the gray bat range by the end of 2050. This scenario may overestimate wind development into the gray bat range because this build-out scenario adds 217 GW more wind capacity than USEIA projected rates (404 GW nationally as opposed to 187.0 GW projected by EIA by 2050). However, the DOE report categorizes EIA’s Energy Outlook as a “business as usual scenario” because the report models wind deployment under current policy conditions and not considering the increasing demand for renewable energy. For example, the Biden administration recently announced that the U.S. will aim to cut carbon emissions by as much as 52% by 2030 (The White House, 2021), which, if realized, will inevitably result in more land-based wind development. While both scenarios provide possible future conditions for wind build-out, it is likely that the true wind build-out will fall within the range of either scenario.

### *Impacts to Individuals*

Tables 11 and 12 report the average annual wind fatalities over the next 30 years. Based on these estimates, we anticipate that average annual fatalities could range from 2,869 to 15,894 depending on the build-out scenario and the facility locations. Cumulatively, by 2050 this Scenario 1 results in the loss of up to 86,083.33 individuals and 476,822.60 individuals under Scenario 2. However, these cumulative nor the annual fatalities estimates represent the actual number of individuals that would be lost over time because the loss of each female is also the loss of her reproductive capacity. Because gray bats only produce a single pup per year, populations may be slow or unable to recover if a significant site is meaningfully impacted by wind facilities.

However, future impacts to gray bats are likely over-estimated in these scenarios. Our estimates are based on the number of little brown bat fatalities from projects that did not attempt to avoid bat fatalities by applying cut in speeds. Wind facilities may pursue ITPs and develop Habitat Conservation Plans (HCPs) that avoid, minimize, and mitigate to fully offset impacts to gray bats, Indiana bats, or both (approximately 90% of gray bat range overlaps with the range of the endangered Indiana bat). We cannot predict how many wind facilities will pursue ITPs and HCPs, but it is unlikely that all future projects will operate without permits and plans, especially those within the range of other federally regulated species such as the Indiana bat.

The extent of impacts to gray bats from future wind facilities may depend on the effectiveness of conservation measures implemented. The Service typically recommends that wind turbines be sited more than 1,000 feet from forested areas to minimize impacts to tree-roosting and foraging bats (USFWS 2011). Because many gray bats roost in caves along waterways, and forage primarily along waterbodies (Moore et al. 2017), siting wind facilities away from waterways would likely reduce the number of gray bats impacted. Limiting operation during high-risk periods, such as nocturnal periods of low wind speeds during the migratory period (Arnett et al. 2011, Baerwald et al. 2009) could also reduce gray bat fatalities. The AWEA has adopted policies to limit blade movement in low-wind speeds (approximately 3.5 m/s) as a voluntary operating protocol that could reduce fatalities up to 30% (AWEA 2015), and Arnett et al. (2011) has estimated that operational curtailment at higher wind speeds (5.0 or 6.9 m/s) could reduce bat fatalities by 44–82%. Studies are also underway regarding promising new methods for reducing fatalities such as acoustic deterrents and forms of smart curtailment<sup>42</sup>.

### *Impacts to Hibernacula and Maternity Populations*

If either build-out scenario is realized, the highest impacts to gray bats could be observed in Missouri (Figures 12 and 13), which includes 15% of the current (2019 winter census data) total gray bat hibernating population, 22% of all Category 1 Biologically Significant summer caves, and 25% of Category 2 Biologically Significant summer

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<sup>42</sup> Smart curtailment is the use of technology to reduce bat fatalities using site-specific data to inform strategic times and conditions in which turbines curtail (real-time curtailment, or algorithm-based curtailment).

caves. The average annual gray bat fatalities in Missouri could range from 1,684 to 5,192 individuals; however, many future Missouri facilities may operate in a manner that minimizes and offsets these fatalities as part of an HCP (as explained above). In addition, the extent of impacts to gray bat populations will largely depend on the specific siting of future wind facilities, proximity of facilities to maternity and bachelor colonies, migratory pathways between hibernacula, caves used during migration, summer caves, foraging sites, and the number of bats present within the colony.

Gray bats hunt over large areas ( $362.2 \pm 24.9$  [SE] km<sup>2</sup>; Moore et al. 2017) during the breeding season and migrate annually between summer roosts, spring staging areas, fall swarm sites and hibernacula. Individuals move short to moderate distances during these relocations (typically <200 miles; 322 km) but one-way movements of over 600 km (373 miles) have been recorded (Elder and Gunier 1978). Therefore, wind facilities constructed in the path of gray bat movements are likely to have a greater impact than those constructed away from travel corridors and hunting grounds. It is important to note that we may be substantially underestimating the potential annual fatalities if facilities are sited near biologically significant maternity colonies or major hibernacula, where very large numbers of bats (e.g., Fern Cave, AL: 1.3 million bats, Coffin Cave, MO: 562,000 bats) congregate and swarm for weeks at a time in the fall prior to entering hibernation and also potentially in the spring building up fat reserves before embarking on migration. Few studies have identified or confirmed migratory pathways and we cannot currently predict exact locations where impacts from wind turbines could be the greatest.

Though we cannot predict exact locations where wind facilities may be constructed, we can evaluate the locations of major hibernacula relative to areas most likely to experience wind energy development (i.e., areas with high wind resources). Using the NREL Wind Prospector tool (NREL 2021), we estimated that 80% of the 15 major hibernacula occur within 15 km (9.3 mi) of areas expected to have the highest wind-generating capacity and 80% of those same major hibernacula are within 15 km (9.3 mi) of areas expected to have the second highest wind-generating capacity. For reference being within 15 km (9.3 miles) of a hibernaculum will impact individual bats migrating to/from and foraging and swarming in proximity to hibernacula. There is only 1 major hibernaculum that does not occur within 15 km of areas having the highest or second highest wind-generating capacity (Pearson Cave, AL).

Gray bat summer caves also occur within high wind-generating capacity areas. Gray bats are unique from many other bat species in the United States in that summer colonies can consist of an extremely high number of individuals (e.g., 200,000 bats at Mary Lawson Cave, Missouri), but are more widely dispersed in summer than in winter periods. Because of the high concentration of individuals around maternity and bachelor caves, wind facilities constructed near colonies also have the potential to affect gray bats. Ninety-one percent of gray bat caves used during the summer and ranked as Category 1 Biologically Significant caves are located within 15 km<sup>43</sup> of areas having the highest

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<sup>43</sup> A 15km buffer was used around caves as this is a commonly observed distance of foraging gray bats from their summer caves (Moore et al. 2017).

wind capacity, and 80% of Category 1 caves are within 15 km of areas having the second highest wind capacity. Of the caves designated as Category 2, 94% are within 15 km of areas having the highest wind capacity, and 94% are within 15 km of areas having the second highest wind capacity. Thus, a large percentage of gray bat colonies occupying biologically significant caves may be exposed to wind facilities in the future. One potential wind facility is considering a location less than 5 miles from a Category 1 Biologically Significant maternity cave with an estimated 73,000 gray bats (August 2015 survey) in Missouri.

Like gray bats, Brazilian free-tailed bats (*Tadarida brasiliensis*) form large maternity colonies that consist of thousands, hundreds of thousands or even over a million bats. At a 68-turbine wind energy facility in Oklahoma, Piorkowski and O'Connell (2010) documented fatalities of Brazilian free-tailed bats and attributed the fatalities to the site's proximity to a large maternity colony. The maternity colony was approximately 15 km (9.3 mi) from the wind facility and contained an estimated 1.5 million Brazilian free-tailed bats (Piorkowski and O'Connell 2010). Of the total 111 bat fatalities documented during the 2-year period, 85% of fatalities were Brazilian free-tailed bats (Piorkowski and O'Connell 2010). The study was conducted during the summer and did not include migratory mortalities. The spatial clumping of mortality within a small area of the wind facility indicates that the collisions were not random, but rather coinciding with landscape features (a ravine in this instance) (Piorkowski and O'Connell 2010). Given the high densities in which gray bats can occur, a similarly sited facility near a gray bat maternity colony could have comparable outcomes.

#### *Impacts to Range-wide Population*

As described above, individual gray bats across the species' range are expected to be killed annually and fatalities will increase as additional wind facilities come onboard in the future. Siting of wind facilities in relation to migration pathways and the locations of hibernacula and maternity colonies will determine the level of impact that wind facilities may have on gray bats range wide. However, wind facilities that pursue ITPs and develop Habitat Conservation Plans that avoid, minimize, and mitigate to fully offset impacts would also greatly benefit the gray bat. Any minimization measures implemented for the benefit of federally listed Indiana and northern long-eared bat will indirectly benefit the gray bat because approximately 90% of the gray bat range is encompassed by the range of these two species. Because gray bats fly at higher wind speeds than Indiana bats and northern long-eared bats, additional minimization measures, such as higher wind cut in speeds, may be necessary to avoid take.

Consequently, we can reasonably conclude that if future wind development is sited near known colonies (maternity or hibernacula) for gray bats, there will be some fatalities. However, the latest data from southwest Missouri (see 2024 Addendum) show there are ways to generate energy and minimize impacts to bats through operating turbines using variable cut-in speeds during sensitive time periods (summer and fall migration). Our BatTool model predicts that the maternity colony closest to the two wind facilities will continue to have positive population growth despite some fatalities.

#### 2.4.5.2 Climate Change

As stated in the 2019 Indiana Bat 5-Year Review (USFWS 2019), climate change has already had observable impacts on biodiversity, ecosystems, and the benefits they provide to society. These impacts include the migration of native species to new areas and the spread of invasive species. Such changes are projected to continue; and without substantial and sustained reductions in global greenhouse gas emissions, extinctions and transformative impacts on some ecosystems cannot be avoided in the long term. More frequent and intense extreme weather and climate-related events, as well as changes in average climate conditions, are expected to continue to damage infrastructure, ecosystems, and social systems that provide essential benefits to communities (USGCRP 2018).

Increasing evidence on the impacts of climate change is a cause for concern as recent increases in global temperature represent one fifth, or less, of expected temperature increases over the next century (Rebelo et al. 2010, Sherwin et al. 2013, O’Shea et al. 2016, USGCRP 2018, Frick et al. 2019). During the last 30 years of the 20th century, evidence suggests that the phenology of organisms, species biogeography, and the composition and dynamics of communities are changing in response to a changing climate (Walther et al. 2002). Details of these impacts to gray bats are explored in the following paragraphs.

Climate influences food availability, timing of hibernation, frequency and duration of torpor, rate of energy expenditure, reproduction, and development rates of juveniles (Sherwin et al. 2013). Warmer climates may benefit females by causing earlier parturition and weaning of young, allowing more time to mate and store fat reserves in preparation for hibernation. Similarly, earlier gestation and parturition may benefit juveniles by providing a longer growth period prior to the breeding season (Burles et al. 2009). Frick et al. (2010) supported this finding by showing that little brown bat pups born early in the summer have higher survival and first-year breeding probabilities than those born later in the summer. In contrast, climate caused increases in disruption of hibernation, extreme weather events, reduced water availability in arid environments, and the spread of disease may also cause significant mortalities (Adams 2010, Hayes and Adams 2017).

Among the most likely future impacts are changes in the range of migratory species, which recently has been reported in 2 European bat species (Lundy et al. 2010, Ancillotto et al. 2016) and the Brazilian free-tailed bat in the southeastern U.S. (McCracken et al. 2018). Similarly, the common vampire bat (*Desmodus rotundus*) is expected to expand its range northward from Mexico to the southern tip and coastal areas of Texas and potentially eastward to Florida where fossil evidence suggests it previously occurred during the Pleistocene epoch (Gut 1959, Mistry and Moreno-Valdez 2008). Dixon (2011) provided genetic evidence that one lineage of little brown bats (*M. lucifugus*) expanded their range northwards after taking refuge in the southeastern U.S. during the last glacial maximum during the Pleistocene. Climate change is also likely to affect the timing of migration. Stepanian and Wainwright (2018) found that Mexican free-tailed bats are

migrating to Bracken Cave in Texas roughly two weeks earlier than they were just two decades ago. They now arrive, on average, in mid-March rather than late March, likely in response to insect prey becoming available earlier in the year.

Changes in temperature may also affect hibernation periods and the availability of suitable hibernacula in the future (e.g., some currently occupied sites may become too warm). Caves and other subterranean habitats are semi-closed systems characterized by a remarkable thermal stability, which are expected to be impacted by climate change (Mammola et al. 2019). There is a direct relationship between external and internal temperature, and thus the stability of subterranean climate. Cave temperatures may respond to changes in ambient temperatures and wind (unpublished data, Missouri Field Office, March 2021) although the magnitude of the response likely varies from cave to cave due to the physical layout and location of the cave (cave length, size of cave opening, the number of openings, and multiple other factors). Temperature data from within Lime Kiln Mine (Hannibal, Missouri) suggests swift temperature responses within the cave to changing ambient wind and temperature (unpublished data, Missouri Field Office, March 2021). Increased variation in climatic extremes raises the possibility of bats emerging from hibernation early or at a greater frequency. Additionally, if internal cave climates are affected by changing ambient conditions, bats may have to rouse more often and/or move to different parts of the cave in response to suboptimal torpor and temperature conditions. Such arousals may result in the use of fat reserves. Resources, especially insect prey, may be limited or variable during periods of early arousal from hibernation. Thus, climate change will likely also affect the future distribution of suitable hibernacula (Humphries et al. 2002).

Large scale precipitation events that result in major floods remain a threat to some gray bat caves and may become a more serious threat in the future due to climate change. During the summer, gray bats tend to occupy and rear young in caves directly adjacent to or close to rivers and large bodies of water. Some of the caves occur at similar altitudes as the waterbodies and are, therefore, prone to flooding during major flood events. For example, following a substantial 2008 flooding event on the Eleven Point River in Oregon County, Missouri, surveyors found 1,435 gray bat skeletons on the walls of Outflow Cave. The bats likely become trapped in the cave and starved to death after the entrance became flooded for an extended time (Jim Cooley, pers. comm. 2020<sup>44</sup>). Another example comes from Beaver Dam Cave in Oklahoma, which exists within the Grand Lake flood pool. When the cave floods early during the maternity season, bats are disrupted and move to nearby Twin Cave. In Georgia, an important summer colony Lost Creek/Chickamauga is vulnerable to flooding but remains occupied.

The frequency of flood events has increased across the southeastern region and across most of the Midwestern U.S. over the past two or more decades (Neri et al. 2019; Konrad et al. 2013), and floods may become a more serious threat to gray bats roosting in caves at low elevations if the frequency and the intensity of floods continue to increase. A continued increase in flood events may result in the abandonment of suitable and

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<sup>44</sup> Jim Cooley, cave cartographer with the Missouri Cave Research Foundation, June 2020.

preferred summer gray bat sites and an overall reduced number of suitable maternity colony caves near waterbodies. The exact number of gray bat caves prone to flooding, and thus the level of risk posed by flooding, is unknown at this time. However, based on informal conversations with each state, we roughly estimate that fewer than 10% of summer sites occur within floodplains and are prone to severe flooding.

Subterranean species are expected to exhibit low tolerance to climatic perturbations due to their evolution in and dependence on a stable environment (Mammola et al. 2019). While some subterranean species may be able to shift their distributional range, Tuttle (1979) found only 5 percent of available caves provided suitable gray bat winter habitat and the species occupies a very small number of hibernacula (Section 2.1.2).

The degree to which negative effects of climate change will be offset by positive effects on other life history features remains uncertain, as does whether population losses in one part of the species' range will be offset by gains in other regions. We have evidence of gray bats using man-made structures for summer roosting, and they may be able to adjust to some changes in roost availability in the future. The degree to which bats can adapt by adjusting their behavioral, ecological, and phenological characteristics also remains largely unknown. Further monitoring and research are needed to better understand the impacts of climate change on gray bats and their habitat.

## **2.5 Synthesis**

Most the gray bats' population-based and protection-based recovery criteria have been achieved. Reclassification Criteria 1, 2, and 4 have been met. Ninety percent of the most populous hibernacula have been protected (Criterion 1). Winter surveys show that there are approximately 5.3 million bats range-wide as of 2019, and range-wide hibernacula and pre-volant summer population trend analyses indicate that gray bat populations appear stable or to be increasing in most states. Criterion 3, or the protection of at least 25% of Priority 2 caves, has been partially met. Many Biologically Significant caves have been protected across the range and across each state to ensure redundancy of protected sites. To date, 70% of the most populous summer colony sites (Category 1 Biologically Significant sites) have been protected range-wide, and more than 50% of these designated sites are protected in each state except for Virginia, which has one Biologically Significant site, which will likely never gain protection because it is a culvert. Lower tier (less populous) Category 2 sites are 43% protected range-wide with >25% protection of sites in each state except for Missouri, which is one site short of meeting the minimum recommended 25% threshold.

As part of the review, we also assessed the status of the gray bat using the five section 4(a)(1) factors (i.e., the "five factor analysis). We evaluated information regarding each factor and its impact on the extinction risk of the gray bat and whether any one or a combination of these factors are causing declines in the species or are likely to substantially negatively affect it within the foreseeable future to such a point that it is at risk of extinction now or likely to become so in the foreseeable future.

Threats related to human disturbance and roost modification and destruction have largely been addressed and no longer adversely affect the species to the degree or extent that they once did. White-nose syndrome was posited as a potential major threat to gray bats in the 2009 5-year review. Surveys conducted over the past 12 years indicate that gray bats do not appear to be susceptible to white-nose syndrome to the same degree as other affected *Myotis*. No mass mortalities have been documented, although to our knowledge, no studies have attempted to determine if sub-lethal impacts occur in gray bats as a result of white-nose syndrome. Based on the very few observed and confirmed WNS affected gray bats and stable population numbers, gray bats appear to be resistant to the disease despite sharing hibernacula with other highly vulnerable species.

Natural calamities, environmental contamination, and impoundment of waterways may still be affecting the species to varying degrees, and in some cases the magnitude of impacts is unknown due to lack or limited number of studies (e.g., pesticide and other chemical contamination, siltation of waterways, reductions of available aquatic food resources). Other factors, such as climate change, may pose a low risk to some caves due to increased frequency and intensity of floods or changes in cave microhabitats.

As wind harvesting energy technology improves, projects are expected to expand into a large portion of the gray bat range. While we can't predict where facilities will ultimately be sited, 80% of hibernacula are within 15 km (9.3 mi) of areas expected to have the highest wind-generating capacity. Additionally, 91% of Category 1 and 80% of Category 2 Biologically Significant summer sites occur within or no further than 9 miles (15 km) of areas that are characterized as having the highest wind-generating capacity. Siting of wind facilities in relation to migration pathways and the locations of hibernacula and maternity colonies will determine the level of impact that wind facilities may have on gray bats range-wide.

Wind facilities that pursue ITPs and develop Habitat Conservation Plans that avoid, minimize, and mitigate to fully offset impacts would also greatly benefit the gray bat. Any minimization measures implemented for the benefit of federally listed Indiana and northern long-eared bat will indirectly benefit the gray bat because 90% of the gray bat range is encompassed by the range of these two species. However, because gray bats fly at higher wind speeds than Indiana and northern long-eared bats, additional minimization measures, such as higher wind cut in speeds, may be necessary to avoid take.

Consequently, we can reasonably conclude that if future wind development is sited near known colonies (maternity or hibernacula) for gray bats, there will be some fatalities. However, the latest data from southwest Missouri (see 2024 Addendum) show there are ways to generate energy and minimize impacts to bats through operating turbines using variable cut-in speeds during sensitive time periods (summer and fall migration). Our BatTool model predicts that the maternity colony closest to the two wind facilities will continue to have positive population growth despite some fatalities. Finally, there is lower risk of wind energy development in the southeast, particularly near the important strongholds for the species in Tennessee, Kentucky, and Alabama.

## **2.6 Summary of Evaluation and Recommendation**

Our review of the best available scientific and commercial information indicates that the gray bat does not meet the definition of an endangered species or a threatened species in accordance with section 3(6) and 3(20) of the Act. This is based on the high number and distribution of gray bats and the stable and increasing trends indicated by recent surveys, the high percentage of protected hibernacula and Biologically Significant caves across the species' range, that the threats identified at the time of listing (primarily human disturbance and roost modification and destructions) have been reduced or addressed, potential threats identified since listing have been found to pose low risk to the species (e.g., WNS) or that there are mechanisms to avoid or reduce impacts (e.g., wind development). Therefore, with this 5-year status review, we recommend that the gray bat be removed from the list of threatened and endangered species under the Act.

### 3.0 RESULTS

#### U.S. FISH AND WILDLIFE SERVICE STATUS REVIEW of the GRAY BAT (*Myotis grisescens*)

**Current Classification:** Endangered

**Status Recommendation resulting from Status Review:**

- Downlist to Threatened  
 Uplist to Endangered  
 Delist (Indicate reasons for delisting per 50 CFR 424.11):  
     The species is extinct  
     The species does not meet the definition of an endangered or threatened species  
     The listed entity does not meet the statutory definition of a species  
 No change needed

**Listing and Reclassification Priority Number:**

**Reclassification (from Threatened to Endangered) Priority Number:**

**Reclassification (from Endangered to Threatened) Priority Number:**

**Delisting (Removal from list regardless of current classification) Priority Number: 4.** The gray bat has a moderate management impact and its delisting is not a petitioned action.

**New Recovery Priority Number: 11.** The change in recovery priority number from an 8 to 11 reflects the low magnitude and non-imminent threats to the species.

**REGIONAL OFFICE APPROVAL:**

**Lead Assistant Regional Director, Fish and Wildlife Service**

Approve **LORI NORDSTROM** Digitally signed by LORI NORDSTROM  
Date: 2025.04.16 15:25:36 -05'00'

## 4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

### Habitat Protection

There are a few Biologically Significant summer caves which remain unprotected (Table A1 and A2). There are also Category 3 and transient caves that lack protection. For example, Category 3 Cripps Mill Cave in Tennessee has suffered at least three disturbance events in which thousands of non-volant gray bat pups died following poorly timed disturbance events by a landowner or recreational cavers (Holliday, pers. comm., 2021).

States should focus on working with private landowners to secure protection for bats through conservation easements, signage, and when deemed truly necessary, gating. We recommend states work together to learn about situations where gating caused gray bats to abandon sites, and in which situations gating has led to successful protection and continued use by a colony. There are various fencing and gating designs that are currently in use (e.g., Photo 2). Use of human-made structures by gray bats appears to be expanding, therefore, impacts to and potential protection mechanisms for these types of structures should also be documented.

**PHOTO 2.** Examples of the “Cheval de Frise” design being used in Missouri to protect caves in steep slopes. Photo Credits: Jim Cooley Cave Research Foundation (right), Vona Kuczynska, Missouri Field Office (left).



### Future Surveys

During our review, we learned about the unique circumstances in each state that determine whether maternity colonies and hibernacula get surveyed, how often, and with what method. We recommend that each state continue to survey major gray bat hibernacula every two years, except for Coffin Cave, Mose Prater Cave, and Fern Cave, which could be surveyed less often because the sites are difficult to survey without causing a major disturbance to bats. We continue to recommend that all the major hibernacula surveys are done concurrently. When not feasible, States should work with adjacent states to determine when bats may interchange caves and considered to be part of a significant cave complex (i.e., sharing a meaningful number of bats that could affect

survey conclusions). Band return data and further genetic studies might be helpful in further classifying caves into complexes.

For the Service to analyze population trends in each state in the future, we recommend that States continue (or begin) to sample summer roost sites and that at minimum, half of Category 1 biologically significant sites are surveyed every year or every other year. The sites should be chosen not solely based on the highest populations but on the accuracy of the sampling effort at the site. Choosing the most populated sites could result in biased interpretations of the data if the sites are supposed to be a representative sampling of all biologically significant caves. If all the sites have relatively equal likeliness in survey accuracy, the sites should be chosen at random. Whenever possible, Category 2 Biologically Significant Caves should also be sampled every year to every other year. At least 25% of the sites should be sampled in each state. The same approach regarding site selection should be applied to these caves as Category 1 caves. Linear mixed effect models allow us to account for potential biases stemming from surveyors and methods. It is very important that the method for each survey is recorded, along with the surveyor's name. In our analysis, we did not have enough information on surveyors to include in our model but could going forward if the information is collected for each survey.

In general, summertime thermal or infra-red video surveys from June 1 to June 30th are strongly preferred, but the equipment is expensive and the surveys and post-processing effort may be time consuming. When possible, surveys should occur in the first half of June, as some populations have been recorded to have volant young in late June. If surveys are conducted after July 1, the surveys should continue during the volant season in future years and as close to the same date as the previous survey. There are no designations for many caves; and whether caves contain nurseries, bachelor colonies, or both is unknown for many Biological Significant caves. We recommend that sites for which the status is unknown are confirmed either through visual inspection of the cave directly after the breeding season to look for juvenile carcasses, or surveys that involve physical capture (e.g., harp trapping) at least once during the breeding season after July 1 to reduce stress to pregnant females. Although the sex ratio of gray bats is likely close to 1:1 (Green et al. 2020), there is a disproportionate number of recorded maternity to bachelor colonies, which likely indicates that some of the presumed maternal colonies may actually be comprised of males.

Especially prior to the year 2000, but in some cases as recently as 2010, summer roost estimates have been obtained from guano or stain areas on ceilings during hibernacula surveys. There is a general consensus that these methods have lower accuracy in predicting population size than other methods. However, guano surveys conducted after the breeding season may be the best available method for estimating population size in areas where infra-red surveys are not feasible. We recommend that guano surveys are reserved for caves where the use of other methods are not feasible.

Unfortunately, estimates assisted by video recordings may still result in data with a low degree of certainty of the true population size. Caves may have multiple entrances that are used by bats, but only one opening is regularly monitored, resulting in under-

estimates. Large caves may have multiple domed rooms and support both a maternity and a bachelor colony during the summer, and thermal/IR surveys cannot differentiate males from females, thereby overestimating maternal use. Populations may fluctuate greatly during the summer, and most surveys are not repeated more than once per summer. In general, summertime thermal or infra-red video surveys from June 1 to June 30th are strongly preferred, but the equipment is expensive and the surveys are time consuming. Repeating thermal or infra-red surveys more than once per summer to determine if large fluctuations occur, and to what degree, is strongly recommended.

## **Future Research**

Of high priority is the need to develop an inexpensive, new software for counting bats recorded with thermal or infra-red cameras. The current system requires outdated tools that can no longer be purchased, and some states have stopped doing summer surveys because their equipment is broken but cannot be replaced. In April 2021, Dr. Laura Kloepper, Associate Professor of Biology at Saint Mary's College in Notre Dame, IN, has been awarded a contract through the U.S. Fish and Wildlife Service Kentucky Field Office and the Kentucky Natural Lands Trust to develop software to automatically track and count bats from cave emergence videos. The software will be developed in 2021 and will be ready for dissemination to States conducting surveys by the end of the summer 2022. The goal of the software is to create a user-friendly interface to automatically count the numbers of emerging bats in thermal, infrared, or standard video recordings. The software will be designed to allow for user flexibility, including defining a region of interest for analysis, specifying a direction in which bats are flying, size threshold, and image adjustments.

As wind energy facilities start to move into the range of the gray bat, studies are needed to understand the impacts of wind facilities to gray bats. These studies will need to assess the fatality risks of gray bats during the breeding and migratory seasons. There is also a lack of knowledge on how landscapes are used during the migratory season, and little information is available to wind energy companies regarding how turbines could be sited to avoid take of gray bats. Studies assessing the migratory pathways of gray bats will be critical to avoid siting of wind facilities in particularly harmful locations.

While gray bats do not appear to be susceptible to white-nose syndrome, there is currently no research being conducted to understand the cause of this resistance. Studies investigating why gray bats are resistant to the fungus may provide insights for reducing impacts to species that are prone to the disease.

As stated in Section 2.2.3, there is a need to identify key populations with high genetic diversity, and more confidently identify past demographic events (e.g., bottlenecks) among gray bat populations. We recommend that a more rigorous genetic study (based on more comprehensive genetic data) be conducted. Lindsay et al. (2015) used eight or fewer loci, which is below the recommended number of loci for detecting population bottlenecks. At this time, underlying gene flow barriers are not well understood. The genetic population structure from Lindsay et al. (2015) indicated that the Alluvial Plain is

not a complete barrier while the cluster assemblies suggest a north:south gene flow barrier. These inconsistencies highlight the need for additional genetic work. Given that identifying such barriers is key to defining management populations, we suggest this be a priority for future genetic work.

### **Other Recommendations**

The gray bat research community should have meetings to share updates and exchange information. The Missouri Field Office will host the Gray Bat Action Team meetings starting in 2021. The meetings are expected to occur once to twice per year.

Additionally, there has been little focus on determining which transient migratory sites are important stopover locations for gray bats. These sites are used every year and provide gray bats safe roosting locations during migration. Spring migration can be especially stressful for bats that have just come out of hibernation and don't have high body fat and energy reserves to withstand stressors to their roosting habitat. States should determine which sites are highly utilized during the spring and fall seasons (e.g., Low Water Bridge Cave in Missouri) and if these sites deserve protection. These sites could be prioritized for gating or acquisition when there are no opportunities to protect higher priority maternity sites or smaller hibernacula.

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## **APPENDIX A:**

### **Status of Recovery Criteria Tasks Recommended in the Gray Bat Recovery Plan**

**TABLE A1.** Protection status of Priority 1, Priority 2 caves from the 1982 Recovery Plan, and Category 1 and 2 Biologically Significant gray bat sites. Biologically Significant sites are summer sites that have been assigned a rank based on the size of their population. This list does not include the 15 major hibernacula. P = permanently protected; NP = not protected.

STATE	Biologically Significant Sites - Category 1	Biologically Significant Sites - Category 2	Priority 1 Sites	Priority 2 Sites	
AL	<b>(3 of 4 Protected)</b> Sauta Cave (P) Cave Springs Cave (P) Hambrick Cave (P) Key Cave (NP)	<b>(2 of 4 Protected)</b> Anderson Cave (P) Indian Cave (P) Weaver Cave (NP) Coon Track Cave (NP)	<b>(3 of 6 Protected)</b> Cave Spring Cave (P) Georgetown (NP) Hambrick Cave (P) Key Cave (NP) Sanders Cave (NP) Sauta Cave (P)	<b>(4 of 7 Protected)</b> Anderson Cave (P) Baker Cave (P) Blowing Springs Cave (NP) Gross Skeleton Cave (P) Guntersville Caverns (NP) Indian Cave (P) Old Blowing Cave (NP)	
AR	<b>(3 of 5 Protected)</b> Bone Cave (P) Buzzard Roost (NP) Horsethief Cave (P)  Horseshoe Cave (NP) Logan Cave (P)	<b>(4 of 6 Protected)</b> Big Creek Cave (NP) Crystal Cave (P) Summer Cave (P)  Huffman Cave (NP) Old Joe Cave (P)  Surprise Pit Cave (P)	<b>(3 of 3 Protected)</b> Bonanza Cave (major hib) (P)* Bone Cave (P) Logan Cave (P)	<b>(15 of 26 Protected)</b> Bald Scrappy Cave (P) Bennett Cave (NP) Blagg Cave (NP)  Blanchard Springs Cavern (P) Brewer Cave (P)  Cave Mountain Cave (Major Hib) (P)* Cave River Cave (NP)  Cave Springs Cave (P) Crane Cave (P)  Crystal Cave (P) Diamond Cave (NP) Fallout Cave (P)  Hankins Cave (NP)	Hell Creek Cave (P) Horsethief Cave (P) Joe Bright Cave (NP) John Eddings Cave (P) Little Bear Cave (NP)  Old Joe Cave (P) Optimus Cave (NP) Ozark Acres Cave (NP) Peter Cave (P) Pigeon Roost Cave (P) Rory Cave (NP) Rowland Cave (P) War Eagle Creek Cave (NP)
FL			<b>(4 of 4 Protected)</b> Geromes Cave (P) Girards/Miltons Cave (P) Judges Cave (P) Old Indian Cave* (P)	<b>(1 of 1 Protected)</b> Sneads Bat Cave (P)	
GA		<b>(3 of 3 Protected)</b> Frick's Cave (P) Lowrey Cave (NP) Chikamauga Creek Cave (NP)	None Assigned	None Assigned	
IL		<b>(1 of 1 Protected)</b> Cave Springs Cave (P)	<b>(1 of 1 Protected)</b> Cave Springs Cave (P)		
KS				<b>(1 of 1 Protected)</b> Storm Sewer/Pittsburg (P)	

STATE	Biologically Significant Sites - Category 1	Biologically Significant Sites - Category 2	Priority 1 Sites	Priority 2 Sites			
	<b>(5/5 Protected)</b>	<b>(4/8 Protected)</b>	<b>(2/5 Protected)</b>	<b>(4/10 Protected)</b>			
KY	Boones Cave (P) Jones Cave (P) Mutters Cave (P) Phil Goodrum Cave (P) Riders Mill Cave (P)	Buzzard Roost/Robertson Complex (NP) Caney Branch Cave (NP) Carpenter Cave (P) Overstreet Cave (NP) Payne/Temple Hill Saltpeter Cave (NP) Smoky Cave (P) Sulphur Creek Cave (P) Watt Cave (P)	Chrismans Cave (NP) Cool Springs Cave (NP) Holland/Carpenter Cave (P) Jesse James Cave (Major Hib) (P)* Overstreet Cave (NP)	Big Sulphur Springs Cave (Pee Dee) (NP) Blowing Cave (NP) Burgess Cave (NP) Caney Branch Cave (NP) Coach Cave (Major Hib) (P)* Daniel Boone Cave (NP) Jones Cave (P) Long Cave (Major Hib) (P)* Payne\Temple Hill Saltpeter Cave (NP) Riders Mill Cave (P)			
	<b>(6/10 Protected)</b>	<b>(2/11 Protected)</b>	<b>(5 of 11 Protected)</b>	<b>(19 of 54 Protected)</b>			
	Bat Cave (Oregon County)(P)	Bat Cave (Dent County) (NP)	Bat Cave (Dent County) (NP)	Adkins Cave (NP)	Devil's Icebox Cave (P)	Indian Ford Cave (NP)	Rantz Cave (NP) River Cave Ha Ha Tonka (Camden County) (P) Rocheport (Boone) Cave (P) Round Spring Cavern (P)
	Mary Lawson Cave (P) Moles Cave (NP) River Cave (Camden County)(P)	Bat Cave (Pulaski County) (NP) Beck Cave (P) Buffalo Quarry (NP)	Beck Cave (P) Coffin Cave (Major Hib) (P)* Great Spirit/Inca Cave (P) Marvel Cave (Major defunct hib)* (NP)	Bat Cave #1 (Miller Co.) (P) Bat Cave #1 (Pulaski Co.) (NP) Bat Cave #2 (Franklin Co.) (NP)	Dry Branch Cave (NP) Estes Cave (NP) Fiery Forks Cave (NP) Fisher Cave (Franklin County) (NP) Fisher Cave (Ralls Co.) (NP) Frankford Cave (NP)	Lewis and Clark Cave (NP) Lower Burnt Mill Cave (P) Martin Cave (NP) Mary Lawson Cave (P) Mayfield Cave (NP) Maze Cave (NP)	Saloon Cave (P) Shamel Cave (NP) Smittle Cave (P)
MO	Rocheport/Boone Cave (P) Toby/Mauss Cave (NP) Smittle Cave (P) Saltpeter Cave (Stone County) (NP) Big Mouth Cave (Oregon County) (NP) Tumbling Creek Cave (P)	Devil's Ice Box (P) El Dorado Spring Sewer (NP) Franford Cave (NP) Grandpa Chipley Cave (NP) Low Water Bridge Cave (NP) Norman Lead Mine (NP) Stinson Cave (NP)	Moles Cave (NP) Mose Prater /Chimney Cave (P) Roaring Srpings Cave (NP) Saltpeter Cave (Stone County) (NP) Toby/Mauss Cave (NP) Tumbling Creek Cave (P)	Bat Cave #2 (Pulaski Co.) (NP) Bat Cave (Laclede Co.) (NP) Bat Cave (Oregon Co.) (P) Bat Cave (Ozark Co.) (P) Blackwell Cave (P) Big Mouth Cave (NP) Carroll Cave (NP) Cat Hollow Cave (NP) Coalbank Cave (P) Cooks Cave (P) Coolbrook Cave (NP)	Freeman Cave (NP) Grandpa Chippley's Cave (NP) Great Scott Cave (P) Hannah Cave (NP) Hilderbrand Cave (NP) Holton Cave (NP) Hunter's Cave (P)	Mary Lawson Cave (P) McDowell Cave (P) McKee Cave (NP) Onyx Cave (P) Piquet Cave (NP) Prairie Hollow Cave (NP)	Saloon Cave (P) Shamel Cave (NP) Smittle Cave (P) Tunnel Cave (NP) Twenty-three Degree Cave (NP) Twin Springs Cave (NP) Unnamed Cave (Cole County) (NP) Windy Cave (P)
	<b>(6 of 7 Protected)</b>	<b>(2 of 3 Protected)</b>	<b>(1 of 1 Protected)</b>	<b>(3 of 3 Protected)</b>			
OK	Anticline (P) Beaver Dam Cave (NP) Boy Scout Cave (P) Charley Owl Cave (P) Christian School Cave (P) Stansberry (January-Stansberry) Cave (P) Twin Cave (P)	Dressler Cave (P) Shifflet Cave (NP) Spavinaw Bat Cave (P)	Stansberry Cave (P)	Charley Owl Cave (P) Linda Bear Paw Cave (P) Spavinaw Bat Cave (P)			

STATE	Biologically Significant Sites - Category 1	Biologically Significant Sites - Category 2	Priority 1 Sites	Priority 2 Sites	
TN	Alexander (P)	Bridgewater Cave (NP)	Bellamy Cave* (major hib) (P)	Alexander Cave* (P)	Harris Cave (NP)
	Ament (P)	Caney Hollow Cave (NP)	Cripps Mill Cave (NP)	Ament Cave (NP)	Herring Cave (P)
	Bat Cave (Hickman County) (NP)	Cripps Mill Cave (NP)	Hubbards Cave* (major hib) (P)	Baloney Cave (NP)	Horner Cave (NP)
	Duds Cave (P)	Jaco Cave (NP)	Indian Cave (NP)	Bat Cave (Hickman Co.) (NP)	Lost Creek Cave (NP)
	Featherfoot (NP)	Oaks Cave (NP)	Nickajack Cave (P)	Bat Cave (Lincoln Co.) (NP)	Markham Cave (P)
	Gallatin Steam Plant Cave (P)	Rose Cave (NP)	Oaks Cave (NP)	Benderman Cave (NP)	Norris Dam Cave (P)
	Grassy Creek (NP)	Trussel Cave (P)	Pearson Cave* (major hib) (P)	Blythe Ferry Cave (NP)	Piper Cave (NP)
			Tobaccoport Saltpeter Cave* (major hib) (P)		Sensabaugh Cave (NP)
	Hound Dog Drop Cave (NP)	Woods Dam (P)		Bridgewater Cave (NP)	Shipman Creek Cave (P)
	Nickajack Cave (P)	Yell Cave (P)	White Buis Cave (P)	Caney Hollow Cave (NP)	Trussell Cave (NP)
	Tobaccoport Saltpeter Cave (P)	Indian Cave (P)		Dud's Cave (P)	Woods Dam (NP)
	Cedar Creek Cave (NP)	White Buis Cave (P)		Eves Cave (NP)	
	Bellamy Cave (P)	Piper Cave (NP)		Featherfoot Cave (P)	
	Pearson Cave (P)			Gin Bluff Cave (NP)	
Rattling Pit Cave (P)			Grassy Creek Cave (NP)		
				<b>(0 of 1 Protected)</b>	
VA				Clinchport Cave (NP)	

## PUBLICATION LIST

A topical list of articles published since the last gray bat 5-year review (2009), sorted by topic.

### Bridges and Roadways

- Cervone, T.H., and R.K. Yeager. 2016. Bats under an Indiana Bridge. *Proceedings of the Indiana Academy* 125(2):91-102.
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### Contaminants

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### Foraging Ecology and Landscape Use:

- Moore, P.R., T.S. Risch, D.K. Morris, and V. Rolland. 2017. Habitat Use of Female Gray Bats Assessed Using Aerial Telemetry. *Journal of Wildlife Management* 81(7):1242-1253.

### Habitat Associations

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### Hibernation Ecology

- Parris, J.D. 2013. An Assessment of Gray Bat (*Myotis grisescens*) Winter Activity and the Potential Implication of This Behavior on Resistance to White-nose Syndrome (WNS) (Unpublished master's thesis). Missouri State University, Springfield, Missouri.

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## Migration

- Samoray, S.T., S.N. Patterson, J. Weber, and J. O'Keefe. 2020. Gray Bat (*Myotis grisescens*) Use of Trees as Day Roosts in North Carolina and Tennessee. *Southeastern Naturalist* 19(3):N49-N52.
- Sasse, B. 2019. Gray Bat Day Roosts in Concrete Barriers on Bridges during Migration. *American Midland Naturalist* 182(1):124.
- Colatskie, S.N., J.T. Layne, C. Gerdes, and L.W. Robbins. 2018. Recent Migratory Movements of Gray Bats (*Myotis grisescens*) in Missouri: Potential to Spread *Pseudogymnoascus destructans*? *Bat Research News* 59(2):11-19.
- Gerdes, C.L. 2016. Gray Bat Migration in Missouri (Unpublished master's thesis). Missouri State University, Springfield, Missouri.

## Monitoring

- Colatskie, Shelly. 2017. Missouri Bat Hibernacula Survey Results from 2011-2017, Following White-nose Syndrome Arrival. Missouri Department of Conservation, Technical Brief.
- Niemiller, M.L., K.S. Zigler, C.D.R. Stephen, E.T. Carter, A.T. Paterson, S.J. Taylor, and A.S. Engel. 2015. Vertebrate fauna in caves of eastern Tennessee within the Appalachians karst region, USA. *Journal of Cave and Karst Studies* 78(1):1–24.
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## Survey and Surveillance Techniques

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## White-Nose Syndrome

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**APPENDIX B:**

**Supplemental Information for  
Population Trend Analysis**

## 1.0 BACKGROUND

Data organization and population trend analysis were conducted by the Missouri Field Office and the University of Missouri (Columbia, MO). The Missouri Field Office contracted Associate Professor Dr. Lisa Webb and post-doctoral fellow Dr. Florian Weller (Missouri Cooperative Fish and Wildlife Research Unit) to carry out the analyses, as the group has extensive experience with modeling bat and bird populations in the Midwest region. Some of the information provided here is also provided in the main body of the review, but Appendix B provides more detail regarding the methods and analyses used in population trends compared to the main document.

## 2.0 METHODS

### Data selection and data screening

Survey count data for both hibernacula and summer roost sites were screened for suitability before inclusion in the trend modeling process. For hibernacula, count data were available for 17 sites. Of these, we excluded three sites. Old Indian Cave (FL, only hibernaculum in state) was removed due to absence of counts greater than seven individuals since 2000. Rattling Pit Cave (TN), a previously unoccupied hibernaculum, had only two counts from 2017 and 2019, and thus could not be modeled although these counts were very substantial (85,955 and 250,890 bats, respectively).

Tobaccoport/Saltpeper Cave (TN) had relatively steady counts since 2010, but none of these reached 1,000 bats, and only the latest two counts were > 400 bats. Therefore, the site was excluded due to supporting very few bats and not being considered a major hibernaculum.

For summer roost sites, we conservatively adopted the minimum of the state-specific thresholds for primary maternity or bachelor site designation (1,000 bats) as a principal criterion. To ensure that we assessed known significant sites where we could detect potential trends using the Mann-Kendall test, we excluded any site that did not have at least one count of  $\geq 1,000$  since 2010 and excluded any site that had less than four counts over the entire analysis period (year 2000-2020). Of the excluded sites, about half (124) had no reported counts since 2010. Application of these criteria yielded an analysis set of 80 summer roost sites out of a total of 348 sites. It's important to note here that a large number of the 348 sites were not maternity or bachelor colonies; many of the sites are transient caves, or caves with fewer than 100 bats that are not monitored regularly by states for that reason.

A small number of individual counts were excluded because no accurate information could be found or inferred about the survey date (month) or the survey method. Prior to analysis, the summer roost data were split by survey month into a pre-volancy set and a post-volancy set. This was based on the expectation that counts at maternity sites would be likely to experience a surge in recorded numbers once newly volant pups and returning males joined the population, creating a season-dependent skew in counts. Counts from May and June were assigned to the pre-volancy set and counts from July and August to the post-volancy set. Summer roost site counts later than August (very few) were excluded as unlikely to be representative.

### Cave complexes

Several groups of hibernacula and summer roosting sites were considered to constitute cave complexes that share a common population which may switch sites between years or over the course of a year; this has implications for trend estimation (Table B2). For summer roost sites, we assigned complexes based on surveyor information received from each state. All sites included in these complexes were three miles or less distant from each other. For hibernacula, one pair of caves was indicated as forming a complex based on field observations (Blanchard Springs Cave and Bonanza Cave, AL; Sharp, pers. comm, 2020<sup>1</sup>). We determined additional likely hibernacula complexes by examining the position of sites on the map. Colatskie et al. (2018) showed through band return data that gray bats might move distances of up to 175 miles between summer and winter grounds, with average travel distances of 35 miles. Elder and Gunier (1978) indicated average one-way migration distances of approximately 125 miles. Thus, taking the average of these migrations, gray bats may migrate an average distance of 80 miles, and may choose between different hibernacula within these distance bands. We used the buffer tool in ArcMap (Version 10.6.1.9270) to draw circles of 80-mile radius around each hibernaculum, and grouped those hibernacula that were overlapped by the same circles. We realize this method is based on assumptions, and we also reviewed population trends for each hibernacula trend individually to determine if placing hibernacula in complexes had any impact on the analysis.

Table B1 shows the complex groups used in the analysis, and the within-complex weight assigned to each cave (for explanation of within-complex weighting see subsection “Weighting”, below). Of the 14 hibernacula, 11 were grouped into 4 complexes and 3 sites were treated separately. Of the 80 summer roost sites, 8 were grouped into 4 complexes and 72 sites were treated separately. Note that one complex (hibernacula Tennessee-1) crosses state lines, consisting of one TN site and one AL site that are 70 miles apart. Since the AL site (Fern Cave) was the only hibernaculum in the state and had only three recorded counts, this complex was assigned to Tennessee and appears as such in the state-level trend estimates.

### Weighting

#### *Method weights*

Surveys of hibernacula and summer roost sites are undertaken using a variety of different methods, which differ in accuracy. For example, an emergence count of less than 500 bats using thermal infrared imaging can be expected to be more reliable than an unassisted naked-eye count of 8,000 bats. This difference in confidence in individual survey estimates can be accounted for in trend estimation using weights. On a scale of 0 to 1, a weight of 1 means that the associated count is likely to be very accurate and should fully influence the model fitting process; a weight of 0 means that the count should be dropped entirely. Intermediate values indicate that we have a relatively greater or lesser confidence in the estimate, and that the count should have a correspondingly adjusted impact on the model. Weights were only used in fitting the linear models; they could not be implemented in the nonparametric (Mann-Kendall) tests (see below).

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<sup>1</sup> Nicholas Sharp, Nongame Wildlife Biologist for North Alabama with Alabama Wildlife and Freshwater Fisheries, July 1, 2020

**Table B1.** Cave complexes used in the trend analysis. Within-complex weights were calculated from the ratios of each site's grand mean within the complex. Note that complex Tennessee-1 contains one AL site (Fern Cave).

<i>Hibernacula</i>				
State	Complex	Sites	Within-complex weight	
AK	Arkansas-1 (all hibernacula in state)	Cave Mountain Cave	0.440	
		Blanchard Springs Cave	0.348	
		Bonanza Cave	0.212	
KY	Kentucky-1 (all hibernacula in state)	Coach Cave	0.399	
		Long Cave	0.181	
		Jesse James Cave	0.420	
MO	Missouri-1	Martin Cave	0.186	
		Bat Cave	0.180	
		Mose Prater Cave	0.634	
TN	Tennessee-1	Hubbards Cave	0.175	
		Fern Cave [AL]	0.825	
<i>Summer roost sites</i>				
State	Complex	Sites	Within-complex weight	
			pre-volant	post-volant
AL	Alabama-1	Collier Cave	0.126	0.152
		Key Cave	0.874	0.848
	Alabama-2	Hambrick Cave	0.996	0.825
		Old Blowing Cave	0.004	0.175
KY	Kentucky-1	Buzzard Roost Cave	0.611	-
		Robertson Cave	0.380	-
OK	Oklahoma-1	Beaver Dam Cave	0.401	0.350
		Twin Cave	0.599	0.650

Table B2 shows the weight classes that were assigned to the different survey methods employed at the assessed sites. Initial weights were provided to several USFWS Field Office biologists and state bat biologists with knowledge of survey methods and their presumed accuracy. Their feedback was incorporated into the final weights. For emergence surveys, weights were further adjusted by number of bats counted, since accuracy of the count would be expected to decrease when counting larger groups. The highest weights (1) were assigned to direct counts of small numbers of hibernating bats, and to thermal and near infrared counts of emerging bat groups below 1,000 individuals. The lowest weight (0.2) was assigned to estimates based on guano deposits only. If multiple methods were reported for a single count, the mean of the applicable weights was used. To improve model convergence, weights were rescaled to sum to 1 at the scale modeled (i.e., at the site/complex, state, or range scale) before fitting each model, by dividing each weight by the sum of all weights in the data set used.

#### *Within-complex weights*

Counts from sites that belong to the same cave complex are assumed to be correlated, in that we regard the combined populations from these caves as a single population that at the time of the survey is split up between the sites in an unknown manner. This is further complicated by the fact that not each site in the complex may have been surveyed each year, making it uncertain what proportion has been sampled of a complex population that may itself be changing in total size.

The within-complex relationship of sites can be incorporated into linear models by including complex identity as a random effect (Thogmartin et al. 2012). This approach was not practical with our data because models using complex identity (as an intercept factor, a slope factor, or both) failed to converge, leaving this aspect unmodeled. Instead, we used an extension of the weighting approach to account for a site's complex membership. For a given year, counts from all sites within the complex were summed to one complex-level population estimate. The count was then assigned a weight based on a) how many of the complex's sites contributed to it, and b) those sites' proportional contribution to the complex population. Proportional contribution was estimated as the ratio of the grand means of counts for each site.

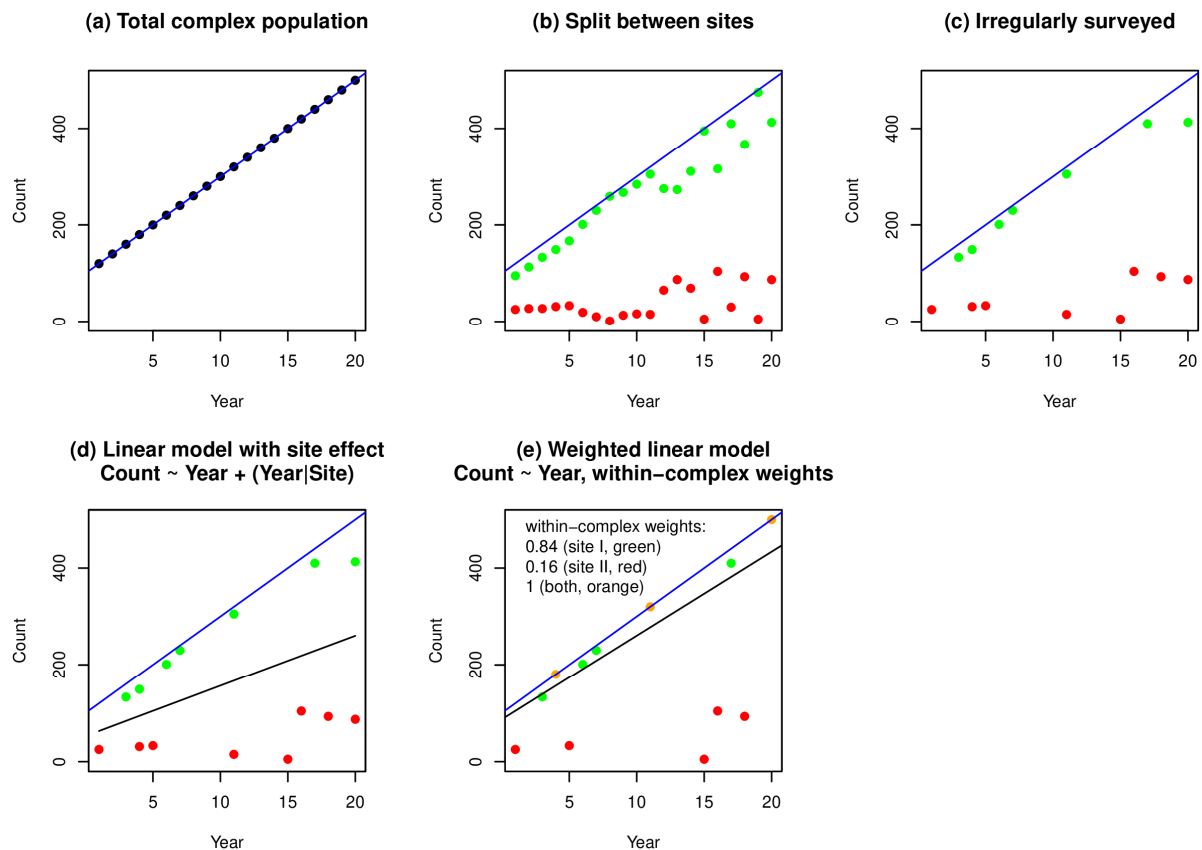
As an example, assume a complex of two sites. The mean count estimate across all surveyed years is 1000 bats for site I, and 4000 bats for site II. The contribution ratio of the sites to the complex population is thus assumed to be  $(1000/5000) : (4000/5000) = 0.2 : 0.8$ . A given count at the complex level is assigned a within-complex weight of 0.2 if it consists of only a site I estimate (we assume that the majority of bats is absent); a weight of 0.8 if it consists of only a site II estimate (we assume that the majority of bats is present); and a weight of 1 if it is the sum of both sites (we assume the entire population was sampled).

Within-complex weights were then factored into the method weights. First, method weights for each summed count within the complex were recalculated based on the proportional contribution of each method to the count's total (e.g., the weight for a summed count consisting of 1000 bats with method weight 1, and 2000 bats with method weight 0.8, is  $1/3 * 1 + 2/3 * 0.8 = 0.858$ ). This was then multiplied with the count's within-complex weight (before normalizing weights to sum to 1). For maternity sites, within-complex weights were computed separately for pre- and post-volant counts, since these were treated as separate data sets. Weights for each complex are shown in Table B2. Simulation tests indicate that this approach may produce more accurate trend estimates at the complex level than accounting for individual sites as a random factor. Figure B1 shows an example fit using a simulated dataset.

**Table B2.** Survey methods used in hibernacula and summer roost surveys, and associated model weights. Higher weight indicates greater confidence in the accuracy of the resulting count estimate.

<b>Hibernacula</b>			
<i>Bats are surveyed inside the cave</i>			
<b>Survey method</b>	<b>Description</b>	<b>Weight</b>	
Direct count	Clusters of < 50 bats, bats counted individually by surveyor	1	
Photo count	Photos are taken of clusters of various sizes; individuals are later counted from images. Confidence is slightly lower because of possible obscuring of bats (bats closer to observer may conceal other bats)	0.9	
Direct estimate	Estimates are taken for clusters of > ~50 bats. Surveyor uses a 1 m × 1 m frame to subdivide very large clusters. If there is variation in cluster density, surveyor further subdivides clusters by high/medium/low density and takes 1 to 3 reference photos of each density level, for which counts are averaged. Confidence is lower because sometimes no averaging is performed, and because visually breaking up clusters into 1m <sup>2</sup> sections can be difficult	0.8	
<b>Summer roost sites</b>			
<i>Bats are surveyed on emergence, or guano estimates are taken in cave</i>			
<b>Survey method</b>	<b>Description</b>	<b>Bats counted</b>	<b>Weight</b>
Thermal/near-IR surveys	Imaging with thermal or near infrared equipment, evaluated by software or by person	< 1,000	1
		> 1,000	0.9
Night vision with near-IR lighting	Count by person with night vision equipment, illuminated with infrared	< 500	0.9
		< 1,000	0.8
		> 1,000	0.6
Night vision w/o IR lighting	Count by person with night vision equipment, no IR	< 200	0.9
		< 1,000	0.7
		> 1,000	0.4
Night vision with video	Imaging with night vision video, count from video by person or software	< 1,000	0.9
		> 1,000	0.7
Unassisted visual count	Bats are counted with naked eye until it gets too dark to see	< 500	0.8
		< 1,000	0.6
		> 1,000	0.3
Visual count with flashlight	Bats are counted with naked eye, using flashlight under cupped hand	< 500	0.7
		> 500	0.6
Guano	An assumed density estimate is based on guano covering a meter squared area (1,828 individuals per m <sup>2</sup> , per Recovery Plan).	Any estimated size	0.2

**Figure B1.** Within-complex weights in a simulated population. (a) The bat population of the complex as a whole with a constant upward trajectory. (b) The population is split between two sites: each year, 1-25% of bats are at site II (red) and the rest at site I (green). The blue line is the true trend of the total population. (c) Both sites are then irregularly surveyed (here, 50% chance for each site / year). This represents the type of data set that might be available for a complex. (d) Population development within the complex can be modeled using a mixed effects model, using year as fixed effect and year within site as a random effect (slope). Black line: predicted population development. (e) Alternatively, site identity within the complex can be accounted for by summing counts for each year and weighting by a within-complex weight estimated from the survey means. This model predicts the true population development with greater accuracy.



### Nonparametric trend test

We attempted to estimate trends in population development at all scales using both linear models and a nonparametric trend test. The Mann-Kendall test (Kendall 1976) is a nonparametric test that ranks sequential counts by assigning a +1 value (current count is larger) or a -1 value (current count is smaller) to each comparison between a given count and each previous count in the series, then summing these values for the entire series. The resulting S-statistic indicates a monotonic increasing trend if it is positive and a decreasing trend if it is negative, based on a two-sided p-value test. We used the implementation of function MannKendall in package Kendall (v2.2; McLeod, 2011) in R v.4.02, under a significance level of  $p \leq 0.05$ . The test requires a minimum of four data points, thus it was not applied in any instance where fewer counts were available. Where no significant trend was detected, the absence of a trend might either indicate that the

population remained relatively stable, or that the variance of the data was too high to yield a reliable estimate. The distinction between these cases of “stable” or “no trend” can be aided by considering the coefficient of variance (CV) of the data series, with a low CV indicating relatively linear (stable) data (Ellison et al. 2003). However, we are not aware of any definitive threshold for making the distinction that is applicable to these ecological survey data, and if desired the assessment should be made on a case-by-case basis by examining the plotted values and the associated statistics.

### Linear models

To derive more rigorous trend estimates, mixed linear models were fit at all scales. Counts were transformed by natural logarithm before modeling to address a strong positive skew in the data. All modeling was carried out in *R* v.4.02. All models contained a main effect of *year* and could have *site* as a random intercept effect, a random slope effect, or both. The following model structures were used, ranked by increasing complexity:

1	$Count \sim Year$	simple linear model, with <i>year</i> as fixed effect
2	$Count \sim Year + (1 Site)$	mixed model, with <i>year</i> as fixed effect and <i>site</i> as a random intercept effect
3	$Count \sim Year + (Year Site)$	mixed model, with <i>year</i> as fixed effect and <i>year within site</i> as a random slope effect
4	$Count \sim Year + (1 Site) + (Year Site)$	mixed model, with <i>year</i> as fixed effect, <i>site</i> as a random intercept effect, and <i>year within site</i> as a random slope effect

Survey method, complex identity, observer identity, and month of the year could be considered as further suitable covariates. However, survey method and complex identity were modeled as weights instead; the data were already split by pre/post-volancy period before analysis; and observer identity was too infrequently reported to be modeled.

The four candidate models were fit using function *lm* in the base package for the simple linear model, or function *lmer* in package *lme4* (v1.1-25, Bates et al. 2020) for the mixed models. All site/complex scale models were simple linear models. Convergence of mixed models was attempted using methods provided by package *optimx* (v2020-4.2, Nash et al. 2020). Models that successfully converged were rejected if *lmer* reported a singular fit (indicative of overfitting). The remaining models were ranked by AICc, and the highest-ranked model was selected. We did not perform averaging of models within a short  $\Delta AICc$  distance of the top-ranked model (Burnham and Anderson 1998) because parameter estimates from models within the suggested range (< 4) were generally very similar. Models were initially fit using unrestricted maximum likelihood to allow comparison by AICc. In the interest of more conservative parameter estimates (taking the degrees of freedom into account), the selected model was then refit using restricted maximum likelihood.

Mean population size at the start and end of the modeled series of surveys, and percentage change over the modeled period, were predicted from the fitted model. Note

that these values represent the predicted means of the sites included at that scale and will almost always be lower than the summed population actually present.

Model residuals were frequently not normally distributed, as indicated by the results of a Shapiro-Wilk test, and/or visibly heteroskedastic. However, the only inference of interest for us with an assumption of normality and homoskedasticity would be the calculation of  $p$ -values based on a normal distribution. We instead derived a robust  $p$ -value for the fixed effect (*year*) by creating a test distribution through bootstrapping from the null model (500 replicates) without the fixed effect ( $count \sim 1$  for the simple linear model, and  $count \sim 1 + \{random\ effects\}$  for mixed models). We used function *PBmodcomp* in package *pbkrtest* v04-8.6 (Halekoh and Højsgaard 2014) for the simple linear model, and function *mixed* in package *afex* (v0.28-0, Singmann et al. 2020) for mixed models (which itself calls *PBmodcomp*). A significance level of  $p < 0.05$  was used to assess the presence of trends in the modeled data.

An estimate of model fit for simple linear models was calculated as  $R^2$  using function *summary* in the base package, but there is no strict equivalent for mixed models. We instead used function *r.squaredGLMM* in package *MuMIn* (v1.43.17, Bartoń 2020) to calculate a “marginal  $R^2$ ” and “conditional  $R^2$ ” following Nakagawa et al. (2017). The marginal  $R^2$  describes the proportion of data variance explained by the fixed effect only, while the conditional  $R^2$  describes variance explained by both fixed and random effects. The latter tends to produce very high values (close to 1) that should not be considered comparable to the ‘classic’ simple linear model  $R^2$ , and are more suitable for comparison between different mixed models. Consequently, these metrics are reported in the tabulated data but not included in the plots. Classic  $R^2$  for simple linear models is however given in site/complex-level plots.

### 3.0 RESULTS – SUPPLEMENTAL INFORMATION

#### *Fitted models*

At the range-wide scale, Mann-Kendall tests (MK) and linear models (LM) could be fitted for all periods (hibernacula counts, pre- and post-volancy counts). All nine states for which any data were available could be fitted with at least one LM and two MK across the three periods. All hibernacula could be fitted with both MK and LM at the state and site / complex level. The single Alabama hibernaculum (Fern Cave) was combined into a complex with a Tennessee hibernaculum (Hubbards Cave), and the complex was assigned to Tennessee; we therefore do not present hibernacula trends for Alabama.

Data for the summer roost sites did not always allow trend estimation for both pre- and post-volancy periods. At the state level, one of nine states (Oklahoma) could be assessed only for pre-volancy, one (Georgia) only for post-volancy, and seven for both periods. Of the 76 individual sites examined, 37 received a trend estimate only for pre-volancy, 24 only for post-volancy, and 15 for both periods.

Except for the LM for Tennessee pre-volancy, the selected (top-ranked) LM always included a *site* effect at state and range scale, about evenly split between models with an

intercept factor ( $1|site$ ) and models with a slope factor ( $year|site$ ). The model with both factors ( $(1|site) + (year|site)$ ) was not selected as the best-fitting model in any case.

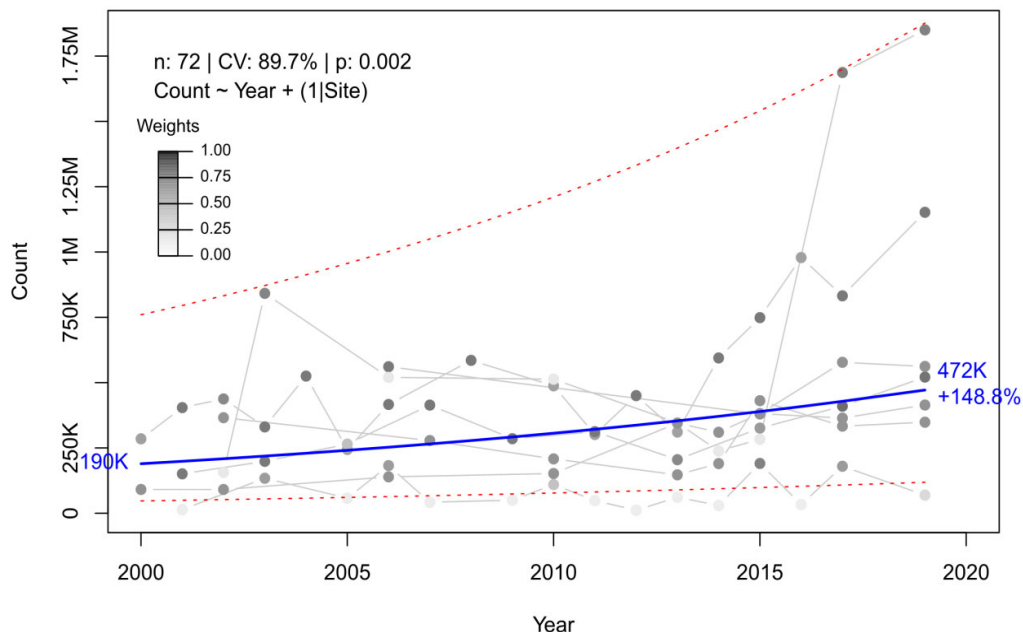
### Supplementary tables and figures

There were no cases where an MK result and a LM result for the same instance showed opposite results. However, in many site-level instances and some larger-scale instances, one of the tests would yield a significant result while the other showed no trend. In such cases, the LM result should generally be regarded as more reliable than the MK result due to the more rigorous method and greater flexibility in parameterization. We therefore treated the LM result as the main trend determinant in any instance, with the MK result to be taken into consideration as a modifier.

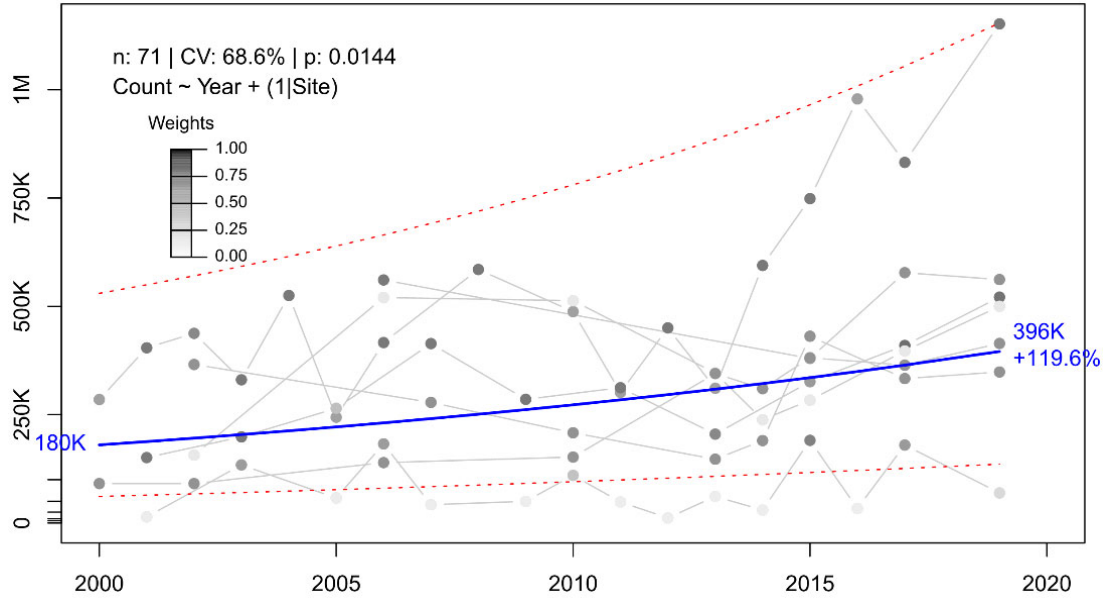
The following tables and figures present results of analyses at the range-wide, state, and site / complex level. Overall trend outcomes at the range-wide and state scale are shown in the main document (Table 3) as are range-wide linear model plots (Figure 3a-d). Table B3 provides information in Table 3, with the addition of results from analyses for complexes.

**FIGURE B2.** Number of individuals counted range-wide at (a-b) hibernacula, (c) pre-volant summer roost sites, and (d) post-volant summer roosts. Individual regression lines in each figure represent count data from individual sites included in the analysis. Counts are shaded by assigned survey method confidence weights (combined method and within-complex weights), with darker shade indicating greater weight. The blue line depicts the predicted regression line from the linear mixed model, and blue text represents predicted starting and ending population sizes and percent change in population size over the modeled period. Red dashed lines represent 95% confidence intervals of predicted values.

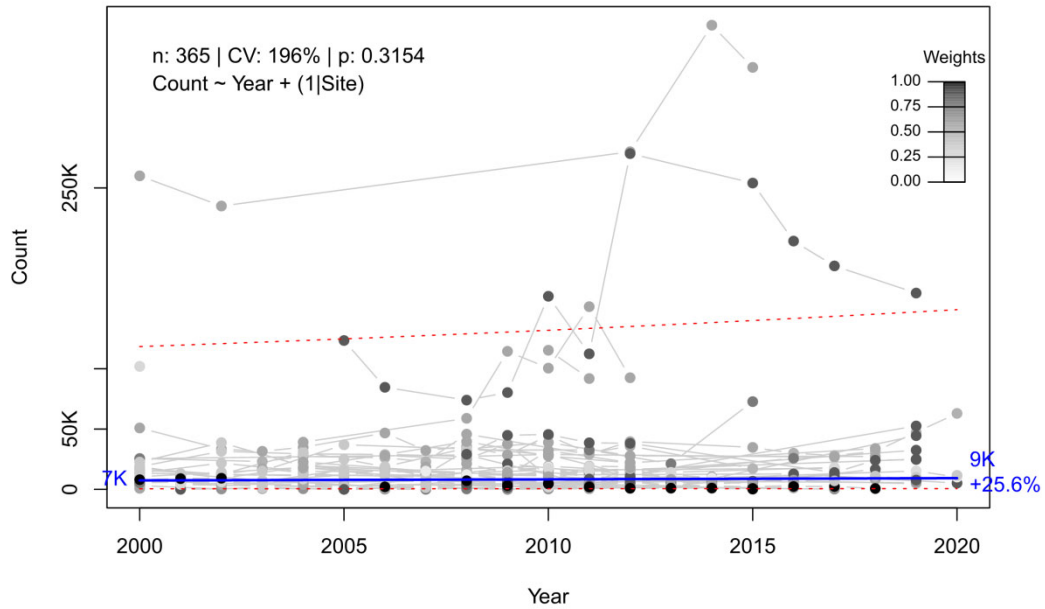
### 3(a). The number of individuals counted range-wide at hibernacula.



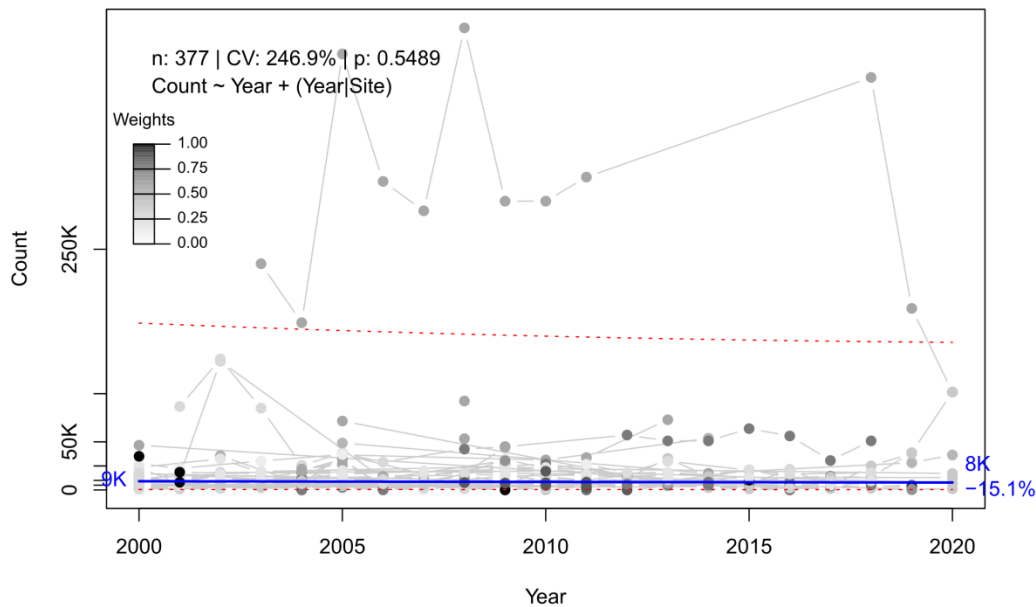
3(b). The number of individuals counted range-wide at hibernacula, excluding Fern Cave.



3(c). The number of individuals counted range-wide during the summer pre-volant period.



**3(d).** The number of individuals counted range-wide during the summer post-volant period.



Rationales for the population trend results are described below. Where no significant trend was detected, the absence of a trend might either indicate that the population remained relatively stable, or that the variance of the data was too high to yield a reliable estimate; this is discussed in the summaries below.

**Range-wide: Overall trend: increasing.** There is a strongly significant increasing trend in the hibernacula LM ( $p = 0.002^1$ ). The data indicate that the hibernacula populations have increased by an average of 148.8% from 2000 to 2020. There is also a significant positive trend ( $p = 0.043$ ) in the summer sites as shown in the pre-volant MK. The pre-volant dataset indicates generally stable populations at most sites, with the 2 most populous sites (by a large margin; Bellamy Cave (TN), Sauta Cave, (AL)) showing increasing trends significant at the site level in both cases). The post-volant data exhibited a similar stable baseline, with Sauta Cave again showing much greater counts but with no significant trend. Figure 4(a-d) depicts range-wide plots with fitted linear models for hibernacula, pre-volant and post-volant data. Because Fern Cave has over 1/4<sup>th</sup> of the gray bat population but only 3 surveys have been conducted, we present the findings both with and without Fern Cave.

**Alabama: Overall trend: inconclusive.** Because the hibernaculum Fern Cave was treated as part of a complex in Tennessee (Fern Cave and Hubbards Cave), no hibernacula estimates were modeled for the state. If Fern Cave was treated as an Alabama site, the hibernacula trend would be strongly positive based on this site alone. However, there are only 3 population estimates available, and these are known to represent partial counts since bats are known to occur in inaccessible parts of the cave. Additionally, two

<sup>1</sup> In statistical testing, the p-value refers to the probability of obtaining test results as extreme as the results actually observed, under the assumption that the null hypothesis is correct, meaning that there is no relationship between variables being studied and, in the case, here, there is no discernable population trend. A very small p-value means that such an extreme outcome would be very unlikely under the null hypothesis.

of the three estimates are not considered highly reliable. Though the summer data for the bachelor colony in Sauta Cave indicate a stable baseline, observation of greater numbers does not result in a significant positive trend.

**Arkansas: Overall trend: increasing.** The statewide hibernacula complex (Cave Mountain Cave, Blanchard Springs Cave and Bonanza Cave) shows a highly significant increasing trend. The positive MK result for the pre-volancy period appears to be driven by a single high count at the bachelor colony at Blanchard Springs Cave and thus should not be considered as highly reliable. Both summer count sets give the impression of highly dispersed data rather than of stable populations. However, there are no indications that the highly significant increasing hibernacula population trends are unreliable; therefore, we consider the Arkansas population to be increasing.

**Georgia: Overall trend: possibly increasing.** No major hibernacula are known to exist in the state. Pre-volant counts from the only 2 caves included in the analysis (Chickamauga Creek Cave and Frick's Cave) show a significant positive trend in the MK test only, although this trend is not significant in the ML ( $p = 0.072$ ). Although the 2 caves are considered too far apart to be treated as a complex, the relative dynamics of the counts among years suggests that they likely represent a complex. However, treatment as a complex would yield a similarly non-significant trend result (data not shown). Post-volant counts are very sparse (5 counts only) and no trend is discernible. Given these considerations, there is weak evidence that the population might be increasing.

**Indiana: Overall trend: increasing.** No major hibernacula are known in the state. The trend estimate is based on post-volant population records from a single maternity site (Sellerbury Quarry Cave) that show a strong increase in population size between 2000 and 2017. The fitted LM for the entire post-volant period shows a highly significant trend ( $p = 0.01$ ).

**Kentucky: Overall trend: increasing.** The statewide hibernacula complex (Jones Cave, Jesse James Cave and Coach Cave) shows a highly significant increase ( $p = 0.008$ ). Every major maternity colony in the state is included in the analysis. While no state-level trend is discernible in the highly dispersed summer data, the result based on hibernacula appears reliable.

**Missouri: Overall trend: inconclusive.** The hibernacula data are inconclusive, consisting of a 3-site complex (Mose Prater Cave, Martin Cave and Bat Cave in Shannon County) and the single-site Coffin Cave, both of which show smaller count fluctuations but appear stable in the longer term. Pre-volant data are widely dispersed, and include a baseline of relatively stable sites and a strong increase at Mary Lawson Cave. Although the post-volant MK test is significant, the linear model does not show a trend. Based on these considerations there is no consistent population trend for the state. It should be noted that based on regular visits to the hibernacula in the state, the Missouri Department of Conservation considers overwintering populations in their hibernacula to be generally stable and not decreasing<sup>1</sup>.

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<sup>1</sup> Shelly Colatskie and Anthony Elliot, Missouri Department of Conservation, January 2021

**Oklahoma: Overall trend: possibly decreasing.** There are no major hibernacula in the state. Most records are from the post-volant period, where the MK test shows a significant downward trajectory ( $p = 0.019$ ). These data are moderately dispersed (CV 48%). Data fitted to the linear model do not show a significant downward trend but visually suggest a downward trajectory for the post-volant period. Bats from Oklahoma likely overwinter in nearby Arkansas hibernacula, which have a significant positive trend. However, the proportion of Oklahoma bats that make up the Arkansas hibernacula is unknown. Therefore, we cannot exclude the possibility that summer colonies in Oklahoma are declining.

**Tennessee: Overall trend: increasing.** The positive hibernacula trend is strongly significant. This trend is partly driven by the inclusion of Fern Cave (AL) but not dependent on it - a model without this site still shows a significant trend ( $p = 0.02$ , data not shown). Pre-volant counts show no significant increase despite the increasing trend in the Bellamy Cave, which influences the pre-volant counts. Post-volant counts show a non-significant decreasing MK trend ( $p = 0.119$ ). In addition to the trend being non-significant, post-volant counts are very low in magnitude compared to hibernacula estimates (modeled population estimates of 3,000 to 12,000 bats in post-volant estimates, as compared to 185,000 to 573,000 bats in hibernacula), and we consider this insufficient evidence to contradict the hibernacula trend estimate.

**Virginia: Overall trend: inconclusive.** No hibernacula are known in the state. There is only 1 site for which sufficient data for analysis were available (Bristol Culvert). This maternity site has 3 pre-volancy and 5 post-volancy records with neither time period showing a significant trend.

**Complexes and Individual Sites:** Missouri-1 and Tennessee-1, and Coffin Cave (MO), show no significant trends. Two Tennessee hibernacula sites also function as maternity colonies, and had pre-volancy survey records. Of these, Pearson Cave shows no significant trend in the summer counts, while those for Bellamy Cave confirm the highly significant positive trend in hibernacula counts. For more information on this separate complex-level analysis that groups nearby caves, see the Methods section.

**TABLE B3.** Population trends for the period 2000-2020 at range-wide and state scale for hibernacula and summer roost sites (split into pre- and post-volant periods), and at site / complex scale for hibernacula. Results are also shown for the two hibernacula sites where pre-volant counts are additionally available. Trends were tested by Mann-Kendall test and by linear models. Overall trend: summary assessment across all periods, see text for details. \*: test  $p \leq 0.1$ , \*\*: test  $p \leq 0.01$ , no trend: no significant test result, NA: no test applied at this level due to insufficient data or inapplicable site category; incr: significant positive trend; poss. incr.: possible positive trend; decr: significant negative trend; indet.: indeterminate assessment.

Scale		Hibernacula		Summer sites pre-volant		Summer sites post-volant		Overall trend
		Mann-Kendall	Linear model	Mann-Kendall	Linear model	Mann-Kendall	Linear model	
<b>Rangewide</b>		* incr	** incr	* incr	no trend	no trend	no trend	incr
<b>State</b>	Alabama	NA	NA	no trend	no trend	no trend	no trend	no trend
	Arkansas	** incr	** incr	no trend	no trend	no trend	no trend	incr
	Georgia	NA	NA	** incr	* incr	NA	no trend	poss. incr.
	Indiana	NA	NA	NA	NA	* incr	** incr	incr.
	Kentucky	* incr	** incr	no trend	no trend	NA	NA	incr
	Missouri	no trend	no trend	no trend	no trend	** incr	no trend	no trend
	Oklahoma	NA	NA	no trend	no trend	* decr	no trend	poss. decr
	Tennessee	no trend	** incr	no trend	no trend	* decr	no trend	incr
Virginia	NA	NA	NA	no trend	no trend	no trend	no trend	
<b>Site / complex (hibern.)</b>	Arkansas		same as state (all sites in one complex)					
	Kentucky		same as state (all sites in one complex)					
	Missouri	Complex Missouri-1	no trend	no trend				no trend
		Coffin Cave	no trend	no trend				no trend
	Tennessee	Complex Tennessee-1	no trend	no trend				no trend
		Bellamy Cave	** incr	** incr	no trend	* incr	NA	NA
Pearson Cave		no trend	no trend	no trend	no trend	NA	NA	no trend

**Legend:**

**\*:** test  $p \leq 0.1$

**\*\*:** test  $p \leq 0.01$

**no trend:** no significant test result. Where no significant trend was detected, the absence of a trend might either indicate that the population remained relatively stable, or that the variance of the data was too high to yield a reliable estimate.

**NA:** no test applied at this level due to insufficient data or inapplicable site category

**incr:** significant positive trend

**poss.incr.:** possible positive trend

**poss.decr.:** possible negative trend

**decr:** significant negative trend

Further supplementary results are presented as tables and plots below. LM = linear model, MK = Mann-Kendall test.

**Tables:**

- Table B4: **MK results**, hibernacula, all scales pre- and post-volant, range-wide and state scales
- Table B5: **LM results**, hibernacula, all scales
- Table B6: **LM results**, pre- and post-volant, range-wide and state scales
- Table B7: **LM - predicted population sizes and relative size change** over the modeled period; hibernacula, all scales; and pre- and post-volant, range-wide and state scales
- Table B8: pre- and post-volant, **trend assessments**, site/complex scale. While detailed results for these sites are not tabulated, the relevant data (n, CV,  $p$ ,  $R^2$ ) are shown in the individual plots (see Figures B7 & B8)

**Figures:**

- Figure B3: **LM results**, hibernacula, state scale
- Figure B4: **LM results**, pre-volant, state scale
- Figure B5: **LM results**, post-volant, state scale
- Figure B6: **LM results**, hibernacula, site/complex scale
- Figure B7: **LM results**, pre-volant, site/complex scale
- Figure B8: **LM results**, post-volant, site/complex scale
- Figure B9: **MK results**, hibernacula and pre-/post-volant, range-wide
- Figure B10: **MK results**, hibernacula, state scale
- Figure B11: **MK results**, pre-volant, state scale
- Figure B12: **MK results**, post-volant, state scale
- Figure B13: **MK results**, hibernacula, site/complex scale
- Figure B14: **MK results**, pre-volant, site/complex scale
- Figure B15: **MK results**, post-volant, site/complex scale

**Table B4.** Mann-Kendall test results at range-wide and state scale for hibernacula and summer roost sites (split into pre- and post-volant periods), and at site / complex scale for hibernacula. n: number of data points (annual means across included sites); CV: coefficient of variation (%); MK score: Mann-Kendall *S*-statistic, sign indicates direction of trend; *p*: *p*-value of test for significance of trend; \*:  $p < 0.05$ , \*\*:  $p < 0.01$

<i>Hibernacula</i>						
<i>Scale</i>		<i>n (means)</i>	<i>CV</i>	<i>MK score</i>	<i>p</i>	
<b>Rangewide</b>		19	48	65	* 0.02	
<b>State</b>	AR	17	48.2	76	** 0.002	
	KY	10	36.9	29	* 0.0123	
	MO	15	104.5	15	0.4884	
	TN	11	66.6	25	0.0617	
<b>Site / complex</b>	AR		same as state (all sites in one complex)			
	KY		same as state (all sites in one complex)			
	MO	Complex Missouri-1	15	77	7	0.7665
		Coffin Cave	4	18	2	0.7341
	TN	Complex Tennessee-1	9	88.3	8	0.4655
		Bellamy Cave	9	52.4	30	** 0.0025
Pearson Cave		8	34.3	2	0.9015	
<b>Summer sites pre-volant</b>						
<b>Rangewide</b>		21	57.3	68	* 0.0431	
<b>State</b>	AL	19	90.5	37	0.2078	
	AR	13	99	32	0.0586	
	GA	9	34.2	26	** 0.0092	
	KY	21	63.8	10	0.7858	
	MO	9	29.3	0	1	
	OK	10	27.4	-11	0.3711	
	TN	17	97.3	40	0.1082	
<b>Summer sites post-volant</b>						
<b>Rangewide</b>		21	47.2	-8	0.8326	
<b>State</b>	AL	16	102.5	-10	0.6853	
	AR	21	124.1	30	0.3812	
	IN	8	43	22	** 0.0094	
	MO	11	63.3	35	** 0.008	
	OK	18	35.1	-63	* 0.0189	
	TN	9	126.6	-24	* 0.0165	
	VI	5	37.8	2	0.8065	

**Table B5.** Linear modeling results for *hibernacula* at range-wide, state and site / complex scale. Where at least two models could be fit, the candidate models are ranked. n: number of data points; CV: coefficient of variation (%); cand.: candidate models in rank order, identified by code (see Methods section); df: degrees of freedom; delta AICc: AICc difference from top-ranked model; structure of selected model: formula of top-ranked model; R2m: marginal R<sup>2</sup> (for mixed models) or standard R<sup>2</sup> (for simple linear models); R2c: conditional R<sup>2</sup> (only for mixed models); *p*: bootstrapped *p*-value of test for main effect significance; \*: *p* < 0.05, \*\*: *p* < 0.01

<i>Hibernacula</i>											
<i>Scale</i>		<i>n</i>	<i>CV</i>	<i>cand</i> .	<i>df</i>	<i>delta</i> <i>AICc</i>	<i>structure of</i> <i>selected</i> <i>model</i>	<i>R2m</i>	<i>R2c</i>	<i>p</i>	
<b>Rangewide</b>		72	89.7	2	4	0	Year + (1 Site)	0.153	0.9945	** 0.002	
				3	6	4.19					
				1	3	43.91					
<b>State</b>	AK	17	48.2	1	15		Year	0.5157		** 0.004	
	KY	10	36.9	1	8		Year	0.5606		** 0.008	
	MO	19	112.8	2	4	0	Year + (1 Site)	0.0035	0.9815	0.5230	
				1	3	8.3					
	TN	26	100.8	2	4	0	Year + (1 Site)	0.2028	0.9853	** 0.008	
				3	6	5.3					
1				3	8.65						
<b>Site / complex</b>	AK	Complex Arkansas-1	same as state (all sites in one complex)								
	KY	Complex Kentucky-1	same as state (all sites in one complex)								
	MO	Complex Missouri-1	15	77	1	13		Year	0.016		0.6727
		Coffin Cave	4	18	1	2		Year	0.0071		0.8982
	TN	Complex Tennessee-1	9	88.3	1	7		Year	0.2982		0.1477
		Bellamy Cave	9	52.4	1	7		Year	0.9325		** 0.002
Pearson Cave		8	34.3	1	6		Year	0.0003		0.9641	

**Table B6.** Linear modeling results for pre- and post-volant summer roost sites at rangewide and state scale. Where at least two models could be fit, the candidate models are ranked. n: number of data points; CV: coefficient of variation (%); cand.: candidate models in rank order, identified by code (see Methods section); df: degrees of freedom; delta AICc: AICc difference from top-ranked model; structure of selected model: formula of top-ranked model; R2m: marginal R<sup>2</sup> (for mixed models) or standard R<sup>2</sup> (for simple linear models); R2c: conditional R<sup>2</sup> (only for mixed models); *p*: bootstrapped *p*-value of test for main effect significance; \*: *p* < 0.05, \*\*: *p* < 0.01

<i>Summer sites pre-volant</i>										
<i>Scale</i>	<i>n</i>	<i>CV</i>	<i>cand</i>	<i>df</i>	<i>delta AICc</i>	<i>structure of selected model</i>	<i>R2m</i>	<i>R2c</i>	<i>p</i>	
<b>Rangewide</b>	365	196	3	6	0	Year + (Year Site)	0.0017	0.999	0.3154	
			4	7	2.08					
			2	4	60.08					
			1	3	357.66					
<b>State</b>	AL	74	209.8	2	4	0	Year + (1 Site)	0.0012	0.9973	0.5429
				1	3	85.3				
	AR	27	134	2	4	0	Year + (1 Site)	0.0072	0.9952	0.3533
				3	6	6.3				
				1	3	14.89				
	GA	16	49.5	1	14		Year	0.2282		0.0719
	KY	114	75.9	3	6	0	Year + (Year Site)	0.0111	0.9979	0.3154
				2	4	24.6				
				1	3	82.54				
	MO	49	123.9	2	4	0	Year + (1 Site)	0.0001	0.997	0.8463
				1	3	48.44				
	OK	12	27	1	25		Year	0.0605		0.4471
	TN	75	184.1	3	6	0	Year + (Year Site)	0.0076	0.9983	0.4556
				2	4	14.94				
1				3	119.2					
<i>Summer sites post-volant</i>										
<b>Rangewide</b>	377	246.9	3	6	0	Year + (Year Site)	0.0009	0.9985	0.5489	
			2	4	4.74					
			1	3	187.47					
<b>State</b>	AL	39	142.6	2	4	0	Year + (1 Site)	0.0009	0.9996	0.3593
				1	3	88.84				
	AR	197	147.7	3	6	0	Year + (Year Site)	0.0003	0.9937	0.978
				2	4	0.31				
				4	7	2.15				
				1	3	50.17				
	GA	5	27.8	1	3		Year	0.0112		0.8383
	IN	8	43	1	5		Year	0.6967		** 0.01
	MO	19	86.5	1	3	0	Year	0.0897		0.2196
	OK	68	48	3	6	0	Year + (Year Site)	0.1068	0.9897	0.1632
				2	4	8.35				
				1	3	56.53				
	TN	34	163.4	1	3	0	Year	0.0874		0.1198
2				4	2.38					
VI	5	37.8	1	3		Year	0.0091		0.8683	

**Table B7.** Starting and end population sizes (mean across all sites at the modeled scale) and percent population change over the modeled period, predicted from linear models. At rangewide and state scale for hibernacula and summer roost sites (split into pre- and post-volant periods), and at site / complex scale for hibernacula.

<i>Hibernacula</i>					
<i>Scale</i>		<i>starting population (predicted)</i>	<i>end population (predicted)</i>	<i>percent change</i>	
<b>Rangewide</b>		189606	471696	+148.8	
<b>State</b>	AR	306581	821000	+167.8	
	KY	188354	446416	+137	
	MO	199315	247251	+24.1	
	TN	185199	572534	+209.1	
<b>site and complex</b>	AK		same as state (all sites in one complex)		
	KY		same as state (all sites in one complex)		
	MO	Complex Missouri-1	86671	118758	+37
		Coffin Cave	526203	507272	-3.6
	TN	Complex Tennessee-1	459635	1371268	+198.3
		Bellamy Cave	82132	464943	+466.1
Pearson Cave		268437	274068	+2.1	
<i>Summer sites pre-volant</i>					
<b>Rangewide</b>		7391	9283	+25.6	
<b>state</b>	AL	7457	9960	+33.6	
	AR	17153	51439	+54.6	
	GA	1783	6244	+250.1	
	KY	6542	11579	+77	
	MO	14962	14237	-4.8	
	OK	12980	11071	-14.7	
	TN	10823	5893	-45.5	
<i>Summer sites post-volant</i>					
<b>Rangewide</b>		9120	7747	-15.1	
<b>state</b>	AL	6121	4159	-32.1	
	AR	4811	5200	+8.1	
	GA	3503	3814	+8.9	
	IN	3646	10632	+206.9	
	MO	15409	35935	+133.2	
	OK	16312	9366	-42.6	
	TN	11884	2573	-78.3	
	VI	5230	5689	+8.8	

**Table B8.** Population trends for summer roost sites (split into pre- and post-volant periods), for the period 2000–2020. Trends were tested by Mann-Kendall test and by linear models. \*: test  $p \leq 0.1$ , \*\*: test  $p \leq 0.01$ , no trend: no significant test result, NA: no test applied at this level due to insufficient data; incr: significant positive trend; decr: significant negative trend.

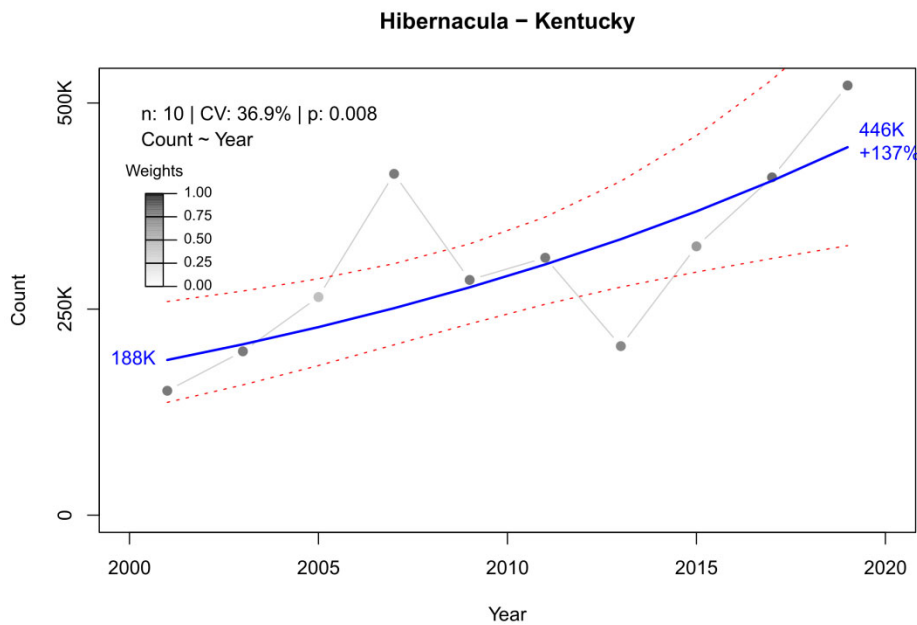
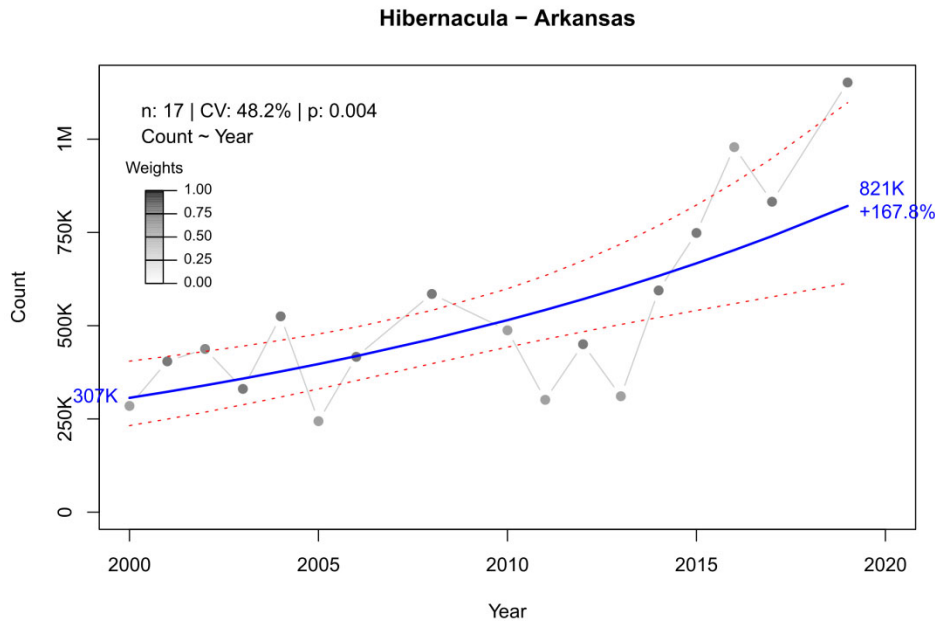
State	Site / complex	Summer sites pre-volant		Summer sites post-volant	
		Mann-Kendall	Linear model	Mann-Kendall	Linear model
Alabama	Complex Alabama-1	no trend	* decr	no trend	no trend
	Complex Alabama-2	** incr	* incr	no trend	no trend
	Anderson Cave	no trend	no trend	no trend	no trend
	Cave Spring Cave	no trend	no trend	NA	NA
	Davis Bat Cave	no trend	no trend	NA	NA
	Indian Cave	no trend	* incr	NA	no trend
	Sauta Cave	no trend	* incr	no trend	no trend
Arkansas	Sublett Springs Cave	no trend	no trend	NA	no trend
	Big Creek Cave	NA	NA	no trend	no trend
	Blanchard Springs Cave	no trend	no trend	no trend	* incr
	Bone Cave	NA	NA	no trend	no trend
	Cave River Cave	NA	NA	no trend	* decr
	Cave Springs Cave	NA	NA	* incr	* incr
	Crystal Cave	NA	NA	* decr	no trend
	Horseshoe Cave	no trend	no trend	no trend	no trend
	Horsethief Cave	NA	NA	no trend	no trend
	Huffman Cave	no trend	no trend	** incr	** incr
	Jones Cave	NA	NA	no trend	no trend
	Logan Cave	NA	NA	* incr	* incr
	Newark Storm Drain	NA	NA	no trend	no trend
Old Joe Cave	* incr	* incr	no trend	no trend	
Summer Cave	NA	NA	no trend	no trend	
Georgia	Chickamauga Creek Cave	* incr	no trend	NA	NA
	Frick's Cave	no trend	no trend	NA	no trend
Indiana	Sellerbury Quarry Cave	NA	NA	** incr	** incr
Kentucky	Complex Kentucky-1	no trend	no trend	NA	NA
	Big Sulphur Cave	no trend	no trend	NA	NA
	Boones Cave	no trend	no trend	NA	NA
	Burgess Cave	no trend	no trend	NA	NA
	Caney Branch Cave	no trend	** incr	NA	NA
	Carpenter Cave	no trend	no trend	NA	NA
	Cool Springs Cave	no trend	no trend	NA	NA
	Jones Cave	no trend	no trend	NA	NA
	Mutters Cave	no trend	no trend	NA	NA
	Overstreet Cave	no trend	* decr	NA	NA
	Phil Goodrum Cave	no trend	no trend	NA	NA
	Ryders Mill Cave	no trend	no trend	NA	NA
	Smoky Cave <sup>1</sup>	** decr	** decr	NA	NA
	Sulphur Creek Cave	no trend	* incr	NA	NA
Temple Hill Saltpeter Cave	no trend	** decr	NA	NA	
Watt Cave	no trend	no trend	NA	NA	

<sup>1</sup>Smoky Cave KY entrance was temporarily blocked by a fallen tree causing bats to exit using a different entrance. The decreasing records are the result of this incident and are expected to rebound now that the tree has been removed.

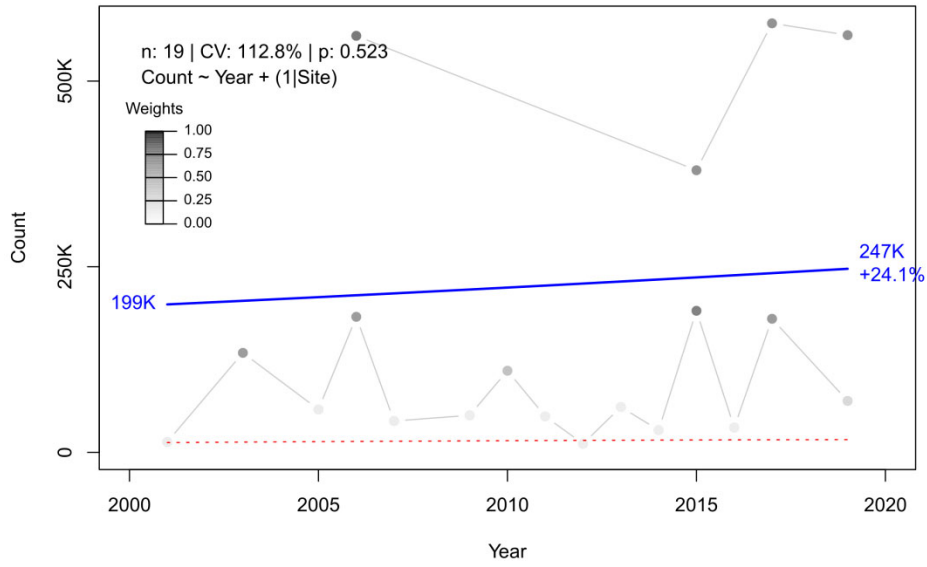
Table B8 continued.

State	Site / complex	Summer sites pre-volant		Summer sites post-volant	
		Mann-Kendall	Linear model	Mann-Kendall	Linear model
Missouri	Devil's Icebox Cave	no trend	no trend	NA	NA
	Grandpa Chippley's Cave	no trend	no trend	NA	NA
	Great Scott Cave	NA	no trend	NA	NA
	Mary Lawson Cave	no trend	* incr	NA	NA
	McDowell Cave	NA	NA	no trend	* incr
	River Cave	no trend	no trend	NA	NA
	Rocheport Cave (Boone)	NA	no trend	NA	NA
	Saltpeter Cave (Stone County)	NA	NA	NA	NA
	Smittle Cave	no trend	* decr	NA	NA
	Toby/Mauss Cave	NA	NA	NA	NA
	Tumbling Creek Cave	no trend	no trend	NA	NA
Oklahoma	Complex Oklahoma-1	no trend	no trend	no trend	no trend
	Anticline Cave	NA	NA	no trend	no trend
	Boyscout Cave	NA	NA	no trend	no trend
	Charley Owl Cave	NA	NA	no trend	no trend
	Christian School Cave	NA	NA	no trend	no trend
	Dressler Cave	NA	NA	no trend	* decr
	January-Stansberry's Cave	NA	NA	no trend	no trend
	Spavinaw Bat Cave	NA	NA	no trend	** decr
Tennessee	Alexander Cave	no trend	no trend	no trend	no trend
	Ament Cave	NA	* decr	NA	no trend
	Bat Cave (Lincoln County)	NA	NA	no trend	no trend
	Bellamy Cave	no trend	* incr	NA	NA
	Caney Hollow Cave	NA	NA	no trend	no trend
	Gallatin Steam Plant Cave	no trend	no trend	NA	NA
	Herring Cave	NA	no trend	NA	NA
	Oaks Cave	no trend	** incr	NA	NA
	Pearson Cave	no trend	* decr	NA	NA
	Rose Cave	no trend	no trend	NA	no trend
	Tobaccoport Saltpeter Cave	no trend	no trend	NA	NA
	Trussell Cave	NA	NA	no trend	no trend
	White Buis Cave	no trend	no trend	NA	NA
Woods Dam Cave	** decr	** decr	NA	NA	
Virginia	Bristol Culvert	NA	no trend	no trend	no trend

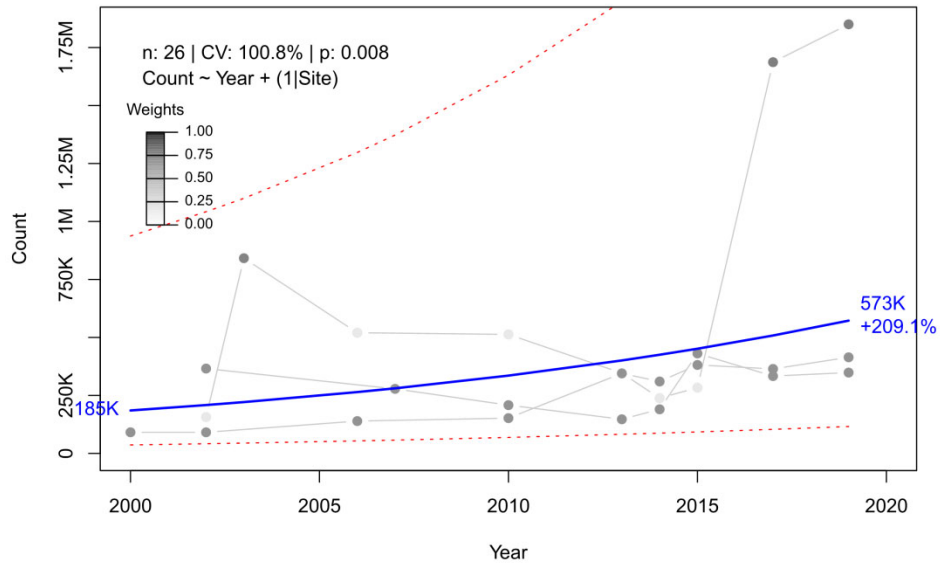
**Figure B3.** Hibernacula state-scale count data with fitted linear model for Arkansas, Kentucky, and Missouri. Counts are shaded by assigned weights (combined method and within-complex weights), with darker shade indicating greater weight. Blue line: predicted regression line, annotated with predicted start and end population sizes and percent change over modeled period; red dashed lines: 95% confidence intervals of predicted values; n: number of data points; CV: coefficient of variation; p: *p*-value of test for presence of trend in predicted values. The fitted model formula is given below these values (see Supplementary Methods).



### Hibernacula - Missouri

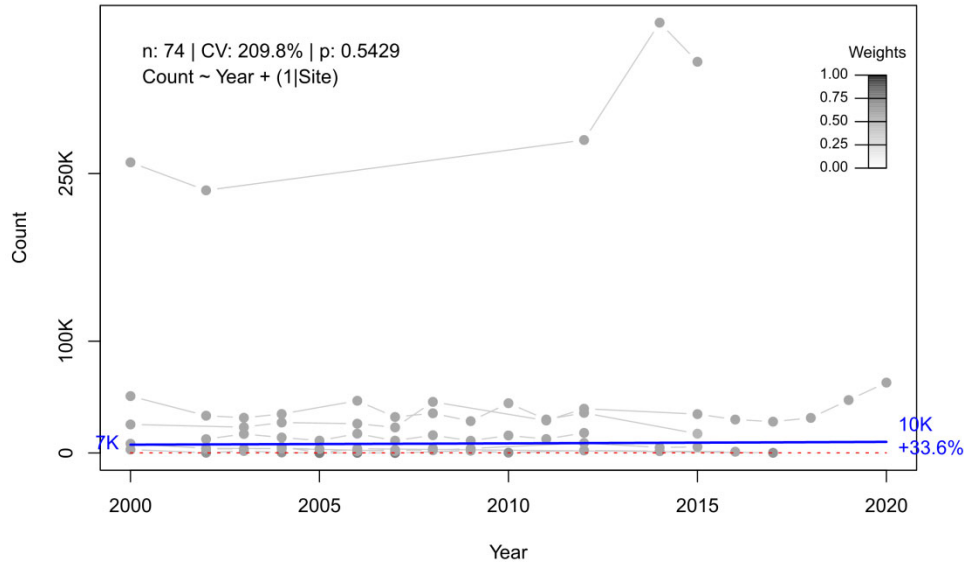


### Hibernacula - Tennessee

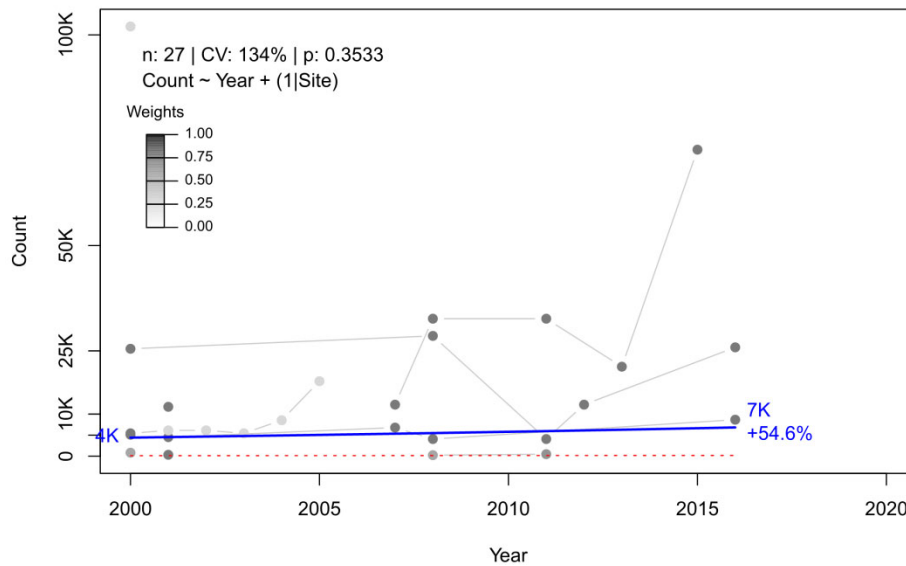


**Figure B4. Summer pre-volant state-scale count data with fitted linear model for Alabama, Arkansas, Georgia, Kentucky, and Missouri.** Counts are shaded by assigned weights (combined method and within-complex weights), with darker shade indicating greater weight. Blue line: predicted regression line, annotated with predicted start and end population sizes and percent change over modeled period; red dashed lines: 95% confidence intervals of predicted values; n: number of data points; CV: coefficient of variation; p: *p*-value of test for presence of trend in predicted values. The fitted model formula is given below these values (see Supplementary Methods).

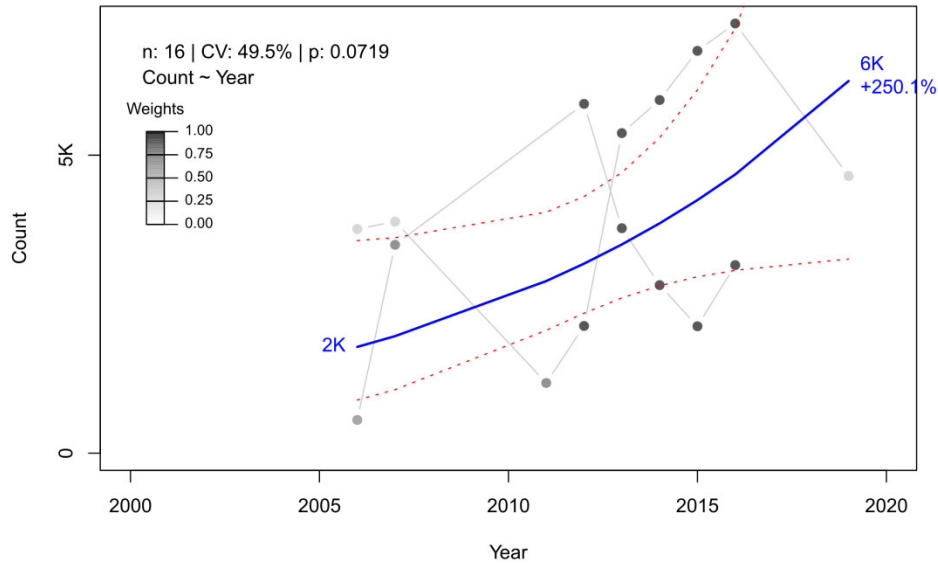
**Summer – pre-volant – Alabama**



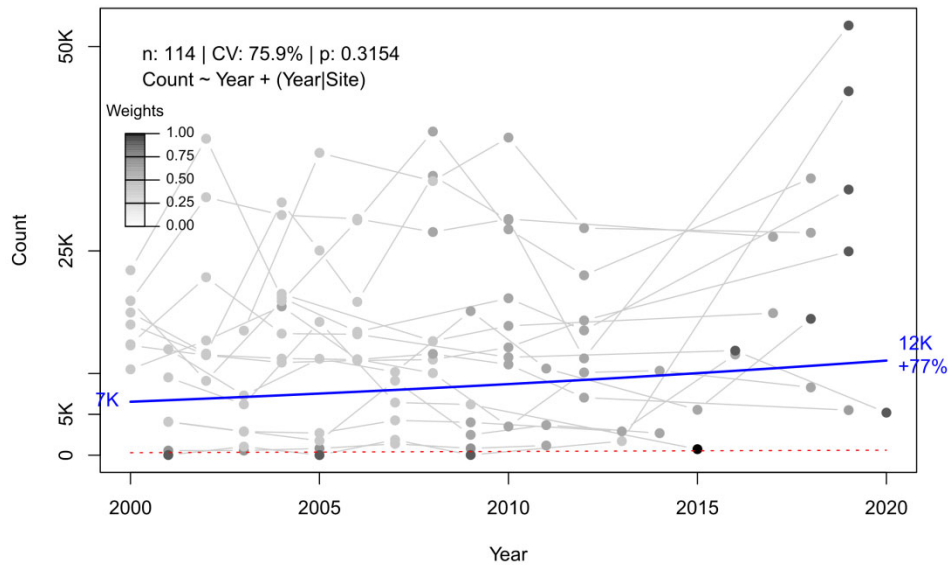
**Summer – pre-volant – Arkansas**



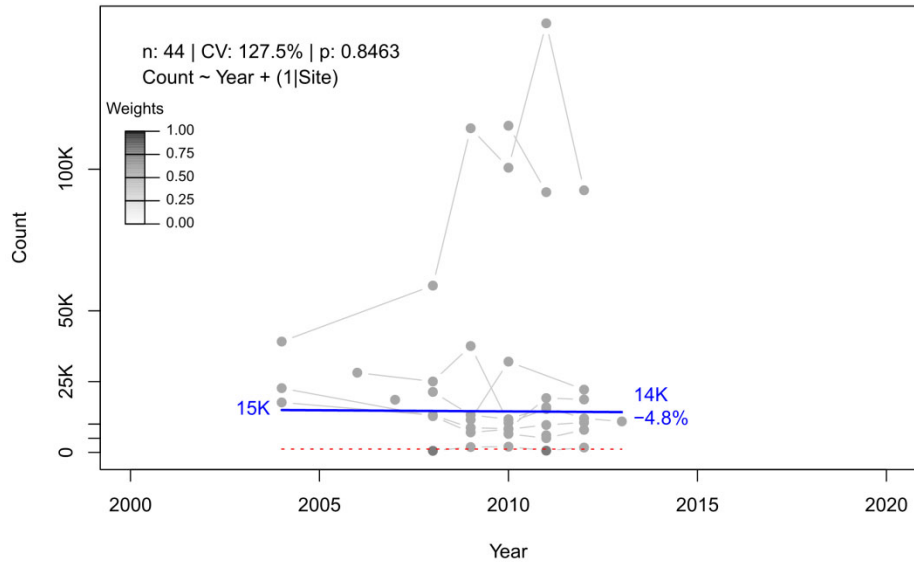
### Summer - pre-volant - Georgia



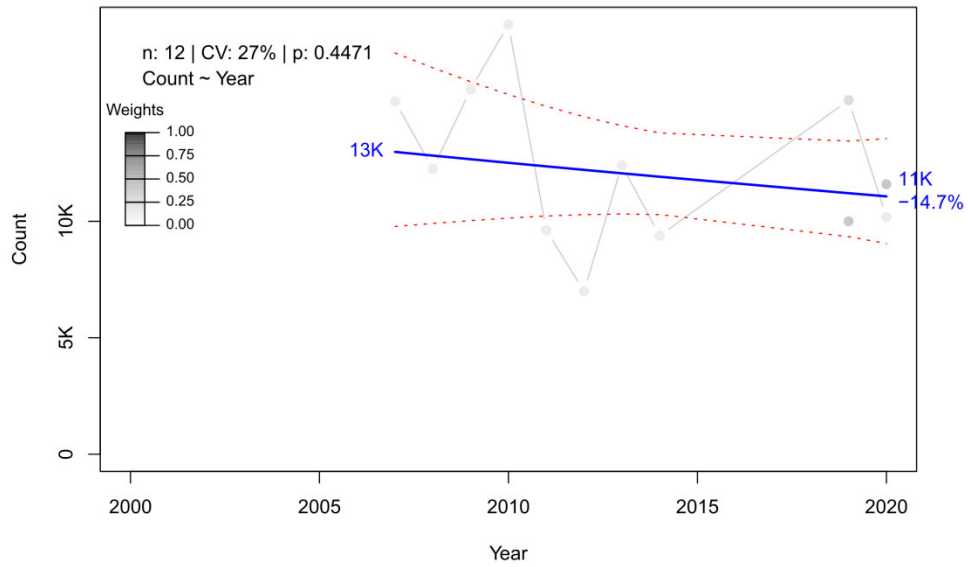
### Summer - pre-volant - Kentucky



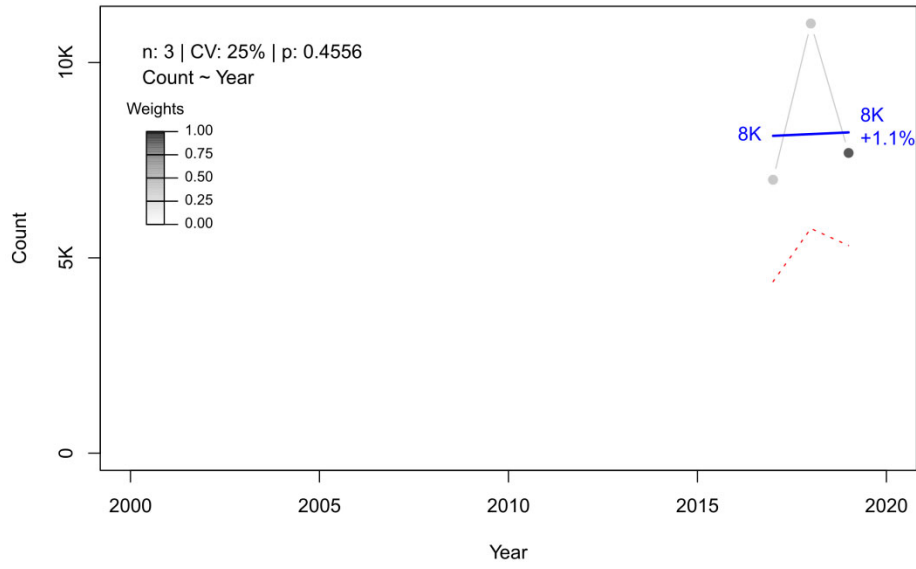
### Summer - pre-volant - Missouri



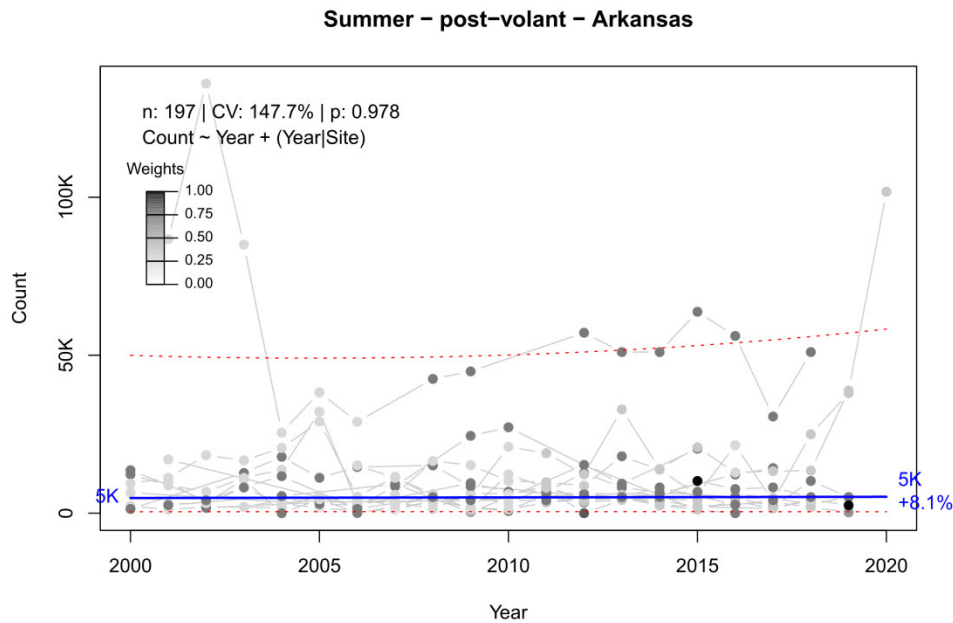
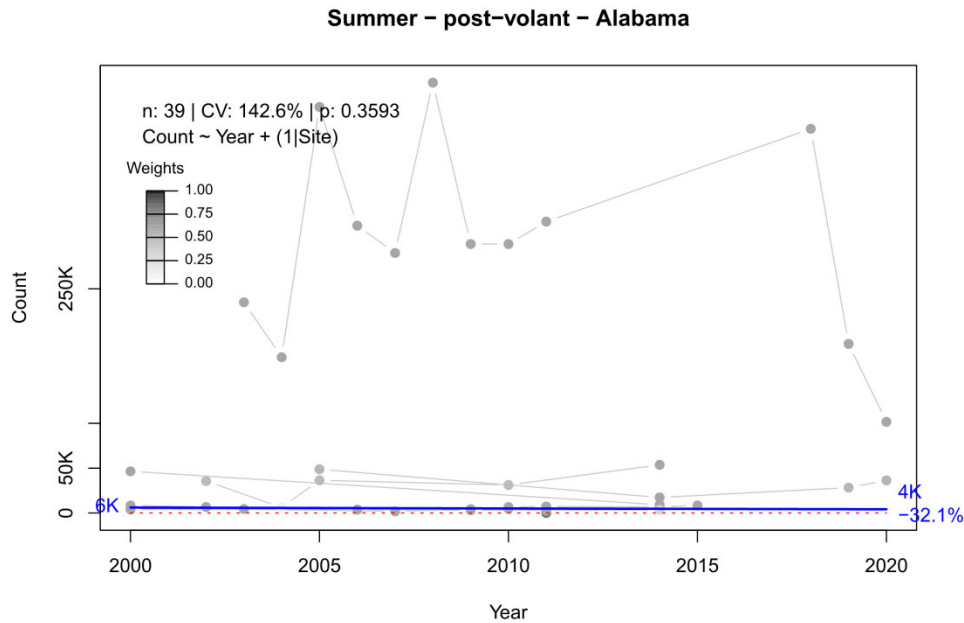
### Summer - pre-volant - Oklahoma



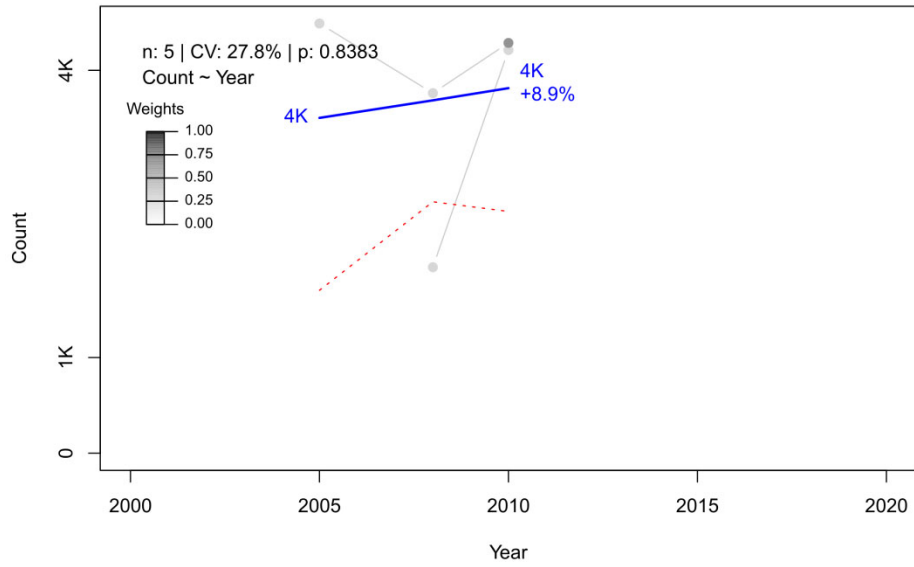
### Summer - pre-volant - Virginia



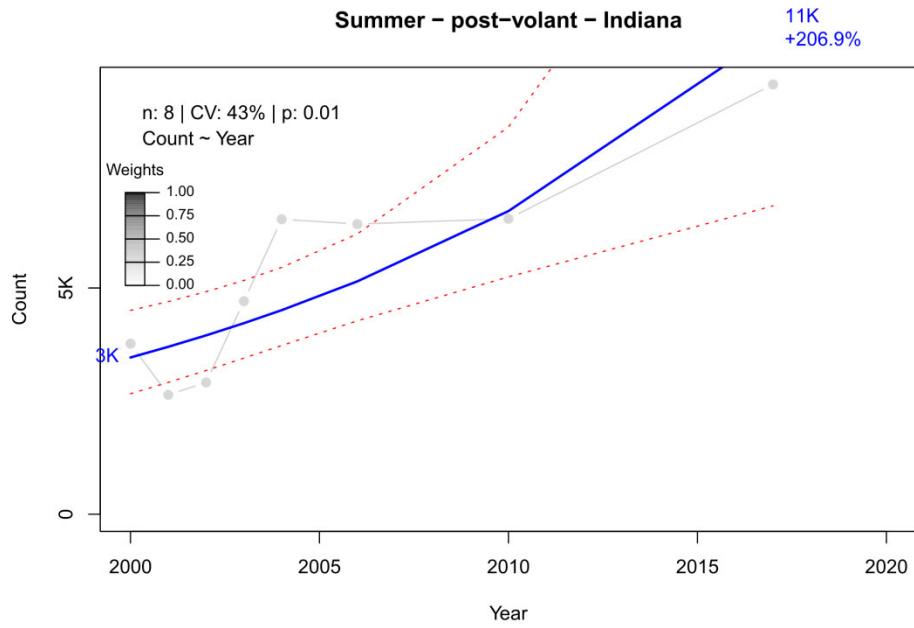
**Figure B5. Summer post-volant state-scale count data with fitted linear model for Alabama, Arkansas, Georgia, Kentucky, and Missouri.** Counts are shaded by assigned weights (combined method and within-complex weights), with darker shade indicating greater weight. Blue line: predicted regression line, annotated with predicted start and end population sizes and percent change over modeled period; red dashed lines: 95% confidence intervals of predicted values; n: number of data points; CV: coefficient of variation; p: *p*-value of test for presence of trend in predicted values. The fitted model formula is given below these values (see Supplementary Methods).



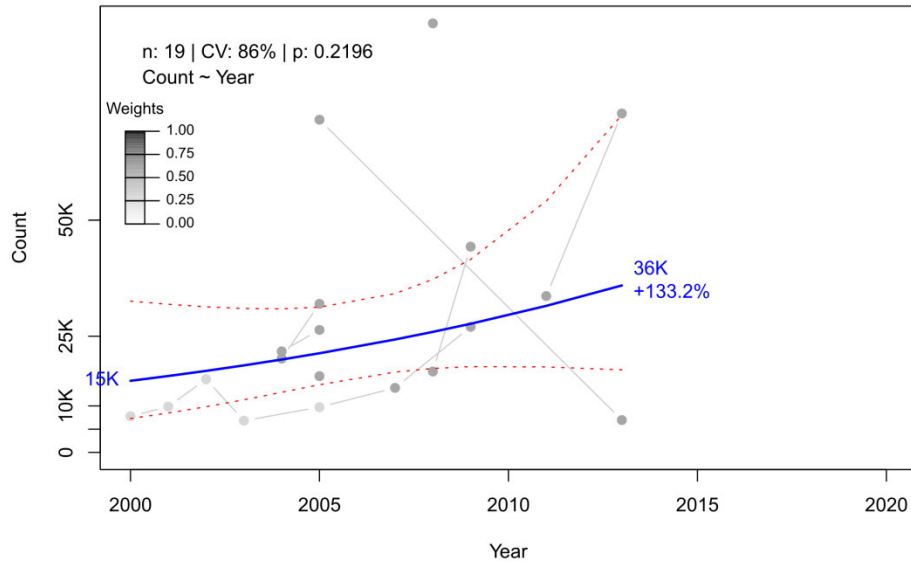
### Summer - post-volant - Georgia



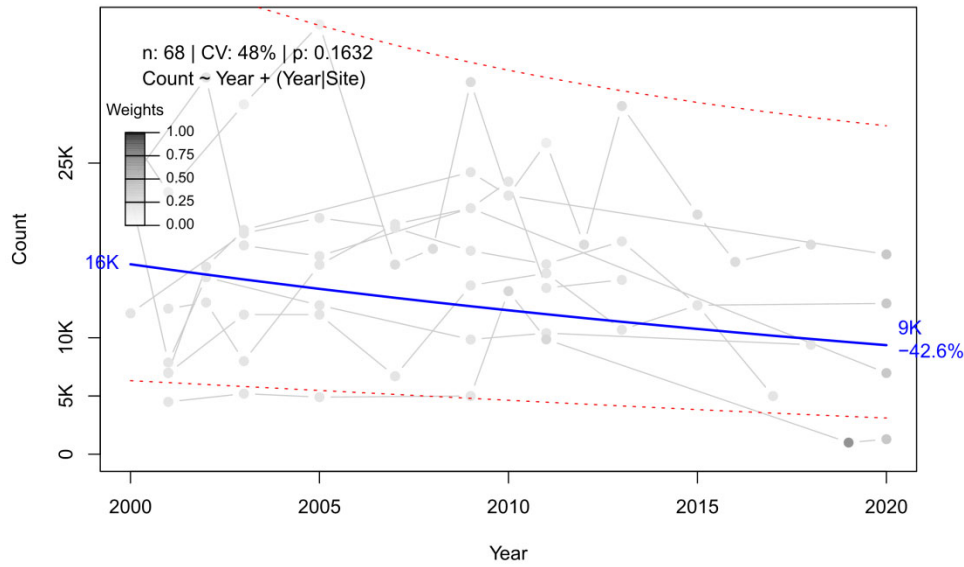
### Summer - post-volant - Indiana



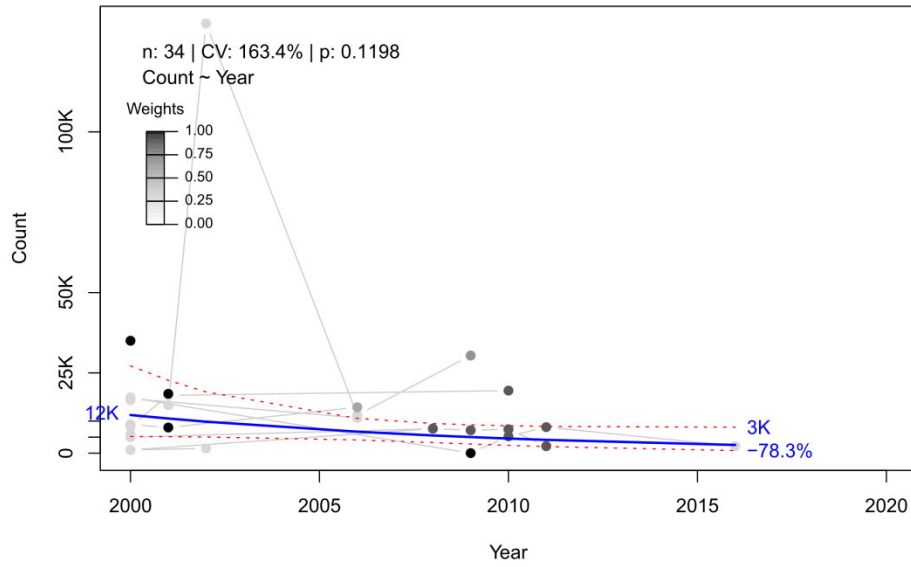
### Summer - post-volant - Missouri



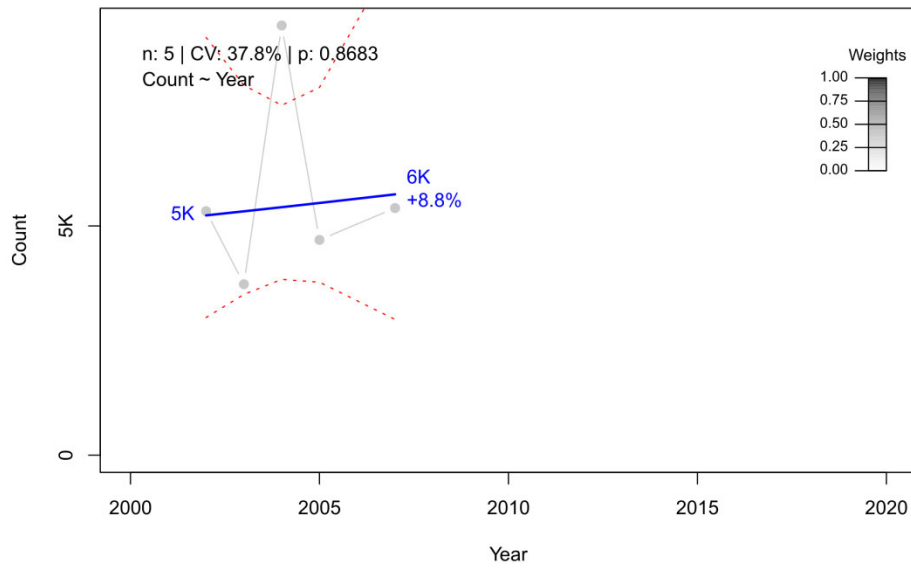
### Summer - post-volant - Oklahoma



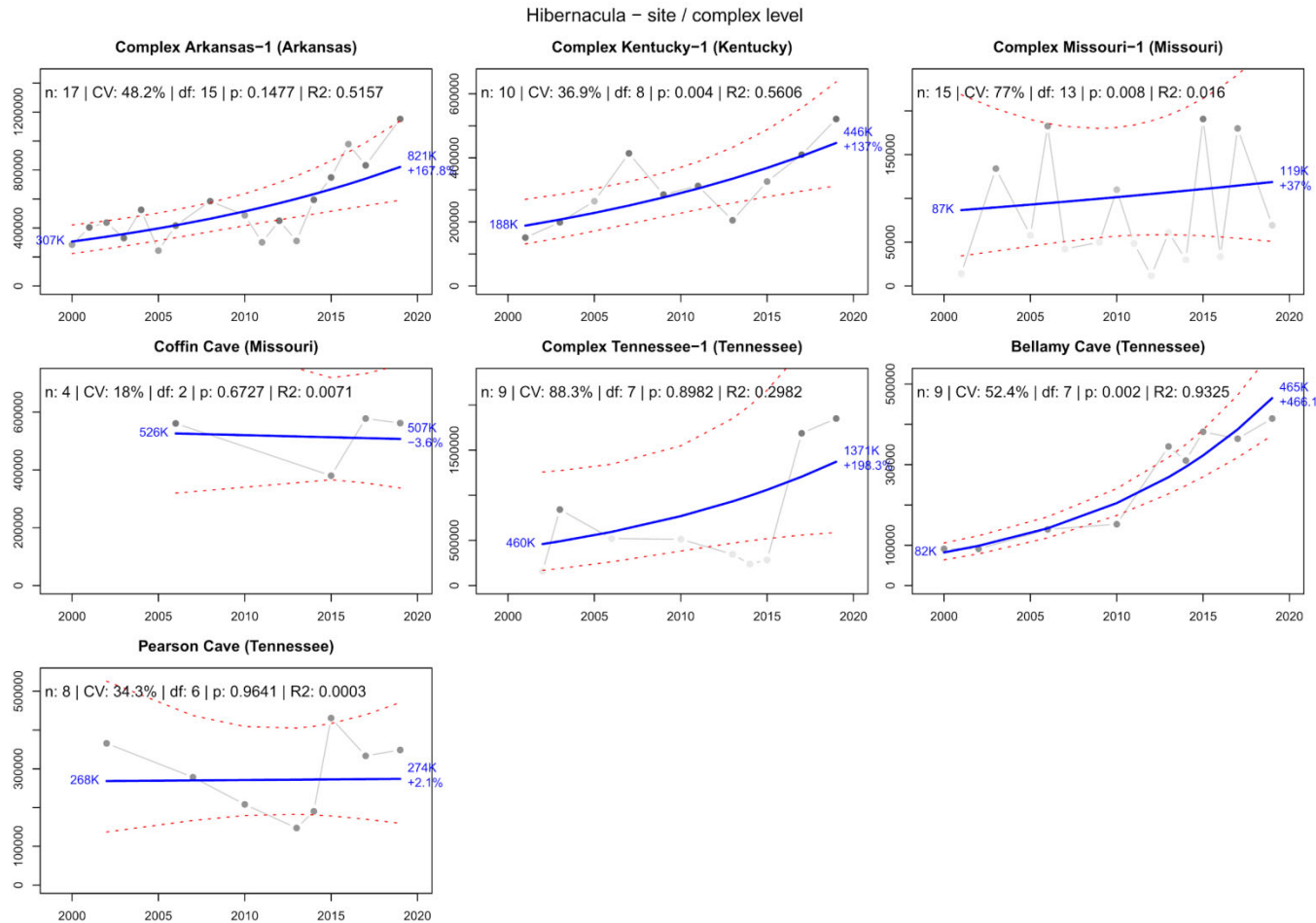
### Summer - post-volant - Tennessee



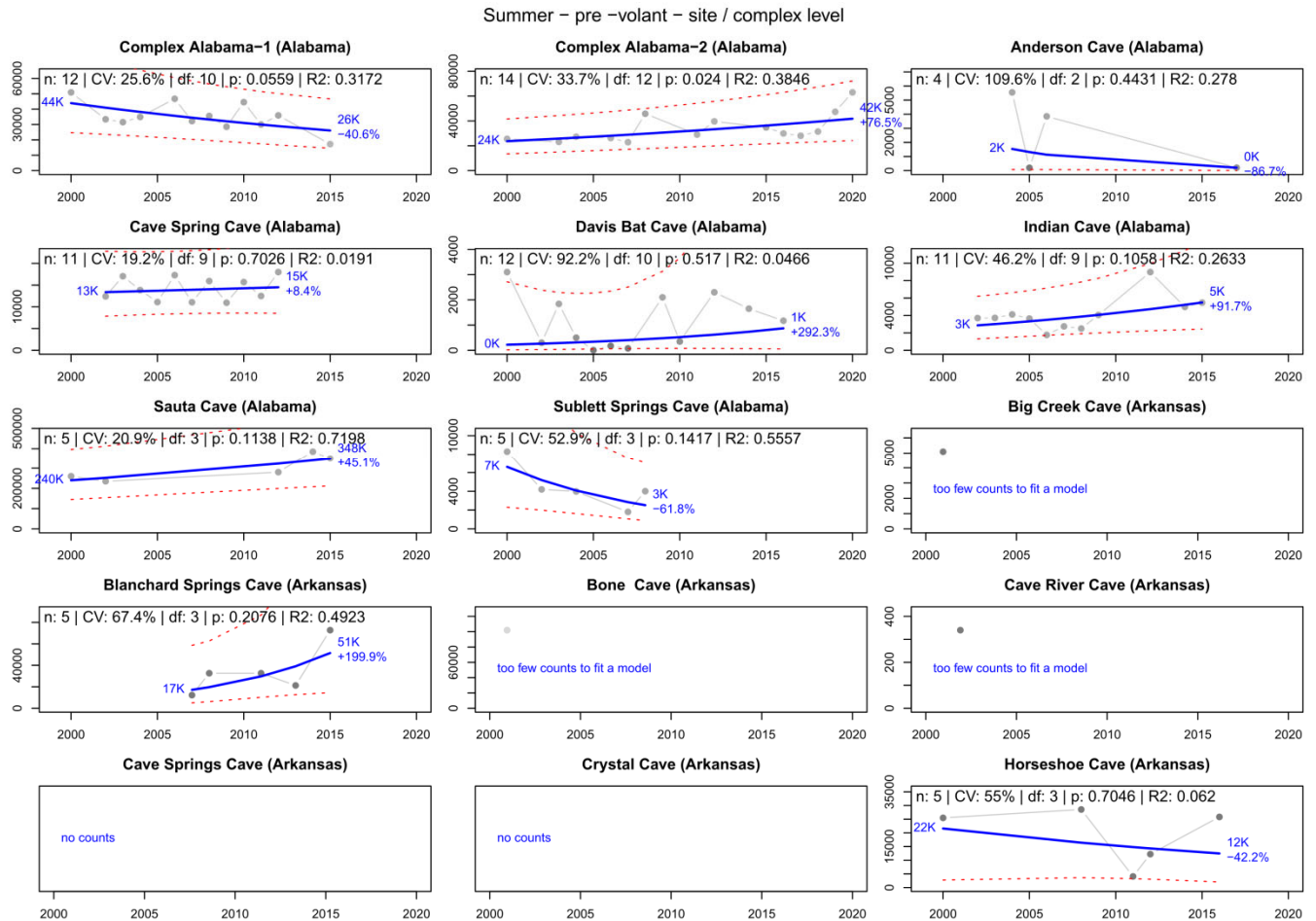
### Summer - post-volant - Virginia



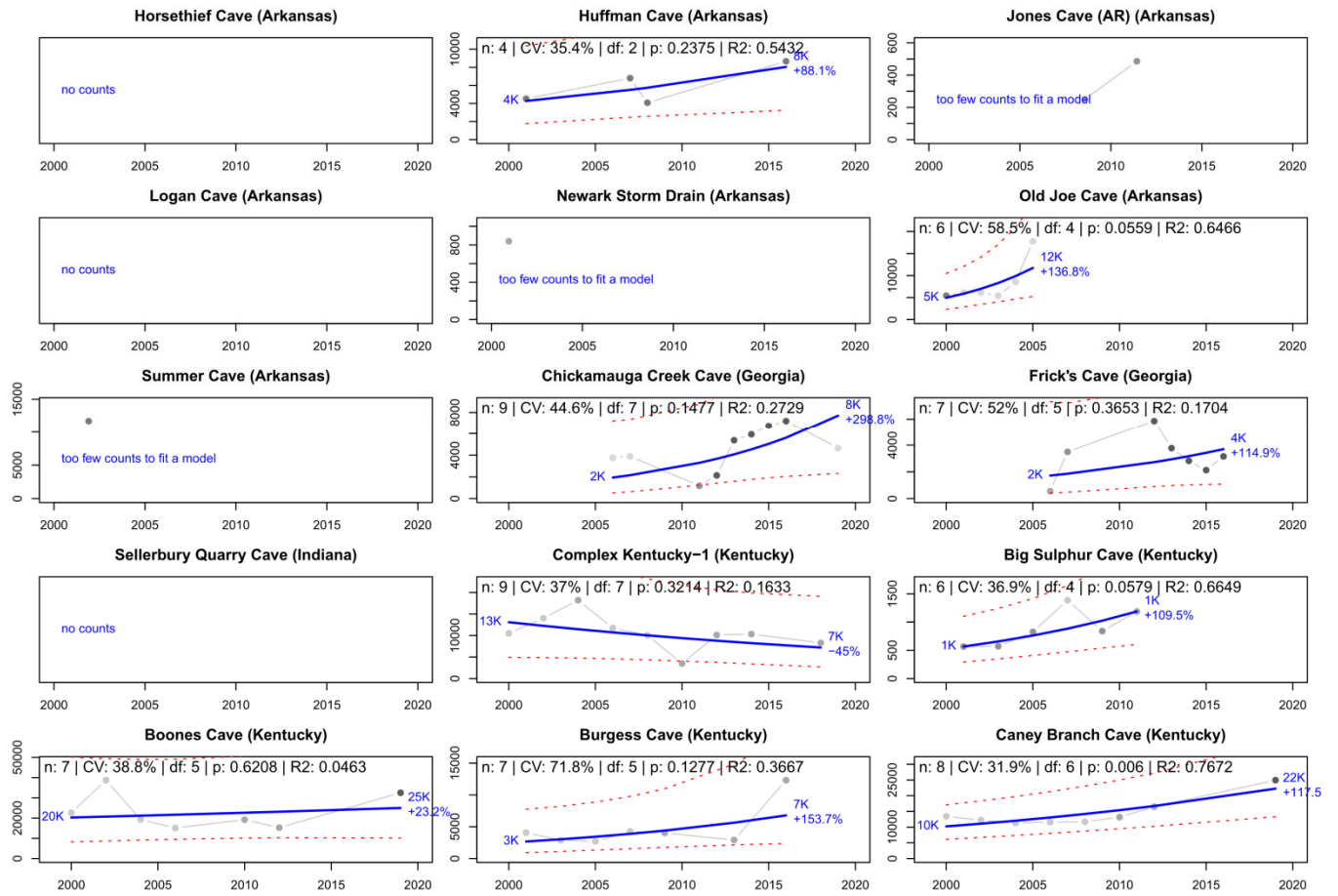
**FIGURE B6.** Hibernacula site / complex-scale count data with fitted linear model. Counts are shaded by assigned weights (combined method and within-complex weights), with darker shade indicating greater weight. Blue line: predicted regression line, annotated with predicted start and end population sizes and percent change over modeled period; red dashed lines: 95% confidence intervals of predicted values; n: number of data points; CV: coefficient of variation; p: *p*-value of test for presence of trend in predicted values. The fitted model formula is given below these values (see Supplementary Methods).



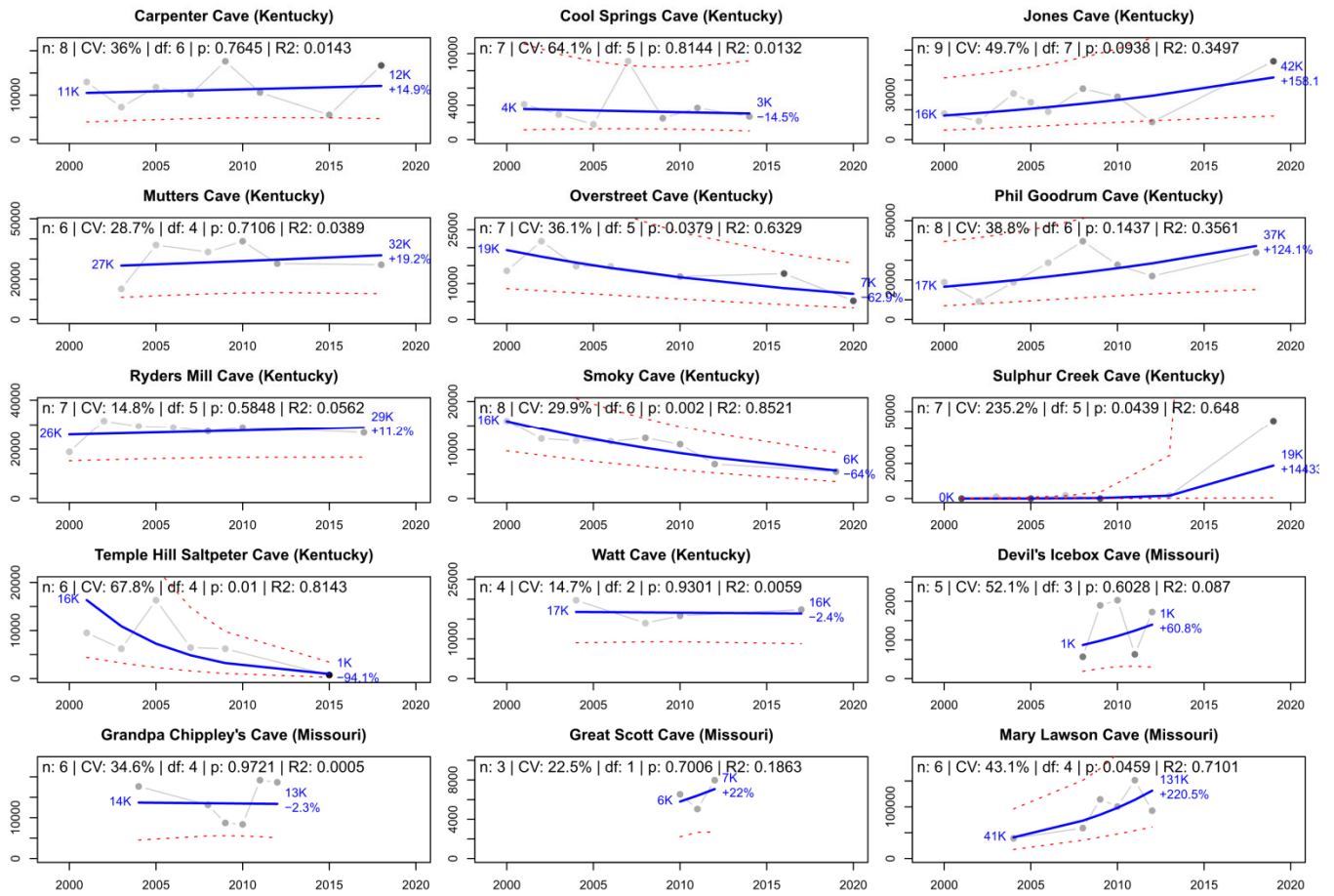
**Figure B7.** Summer pre-volant site / complex-scale count data with fitted linear model. Counts are shaded by assigned weights (combined method and within-complex weights), with darker shade indicating greater weight. Blue line: predicted regression line, annotated with predicted start and end population sizes and percent change over modeled period; red dashed lines: 95% confidence intervals of predicted values; n: number of data points; CV: coefficient of variation; p: *p*-value of test for presence of trend in predicted values.



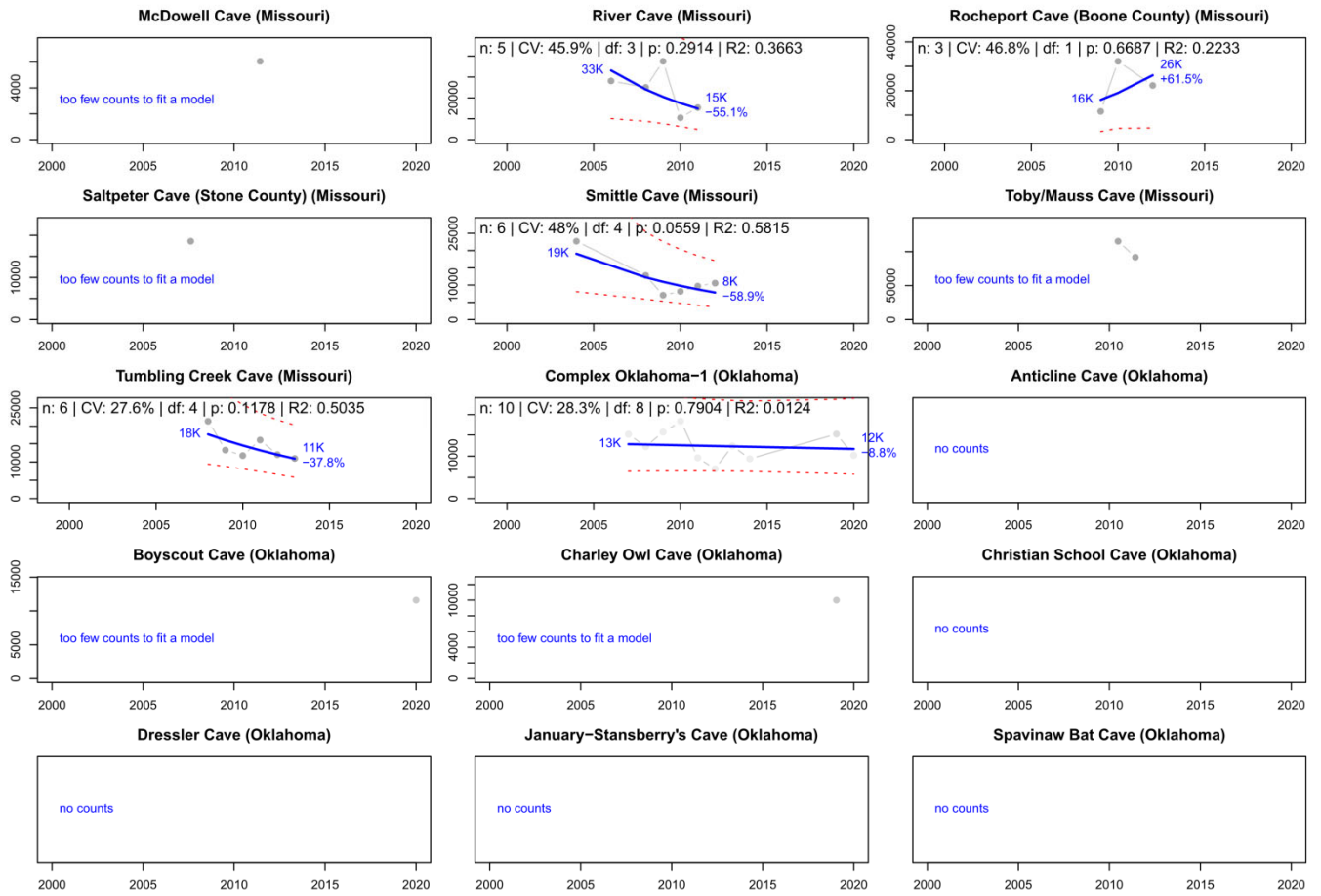
Summer – pre – volat – site / complex level



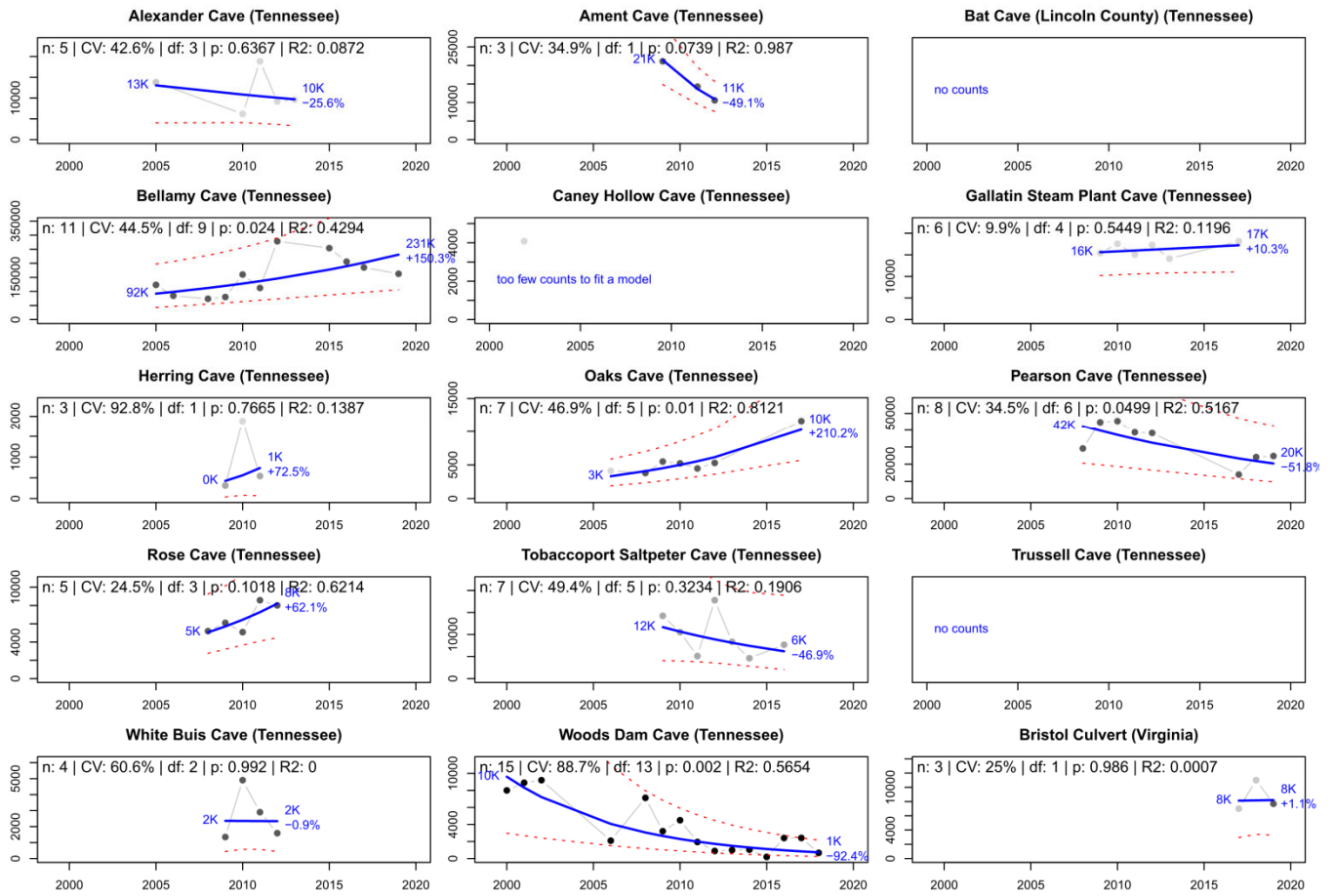
Summer – pre –volant – site / complex level



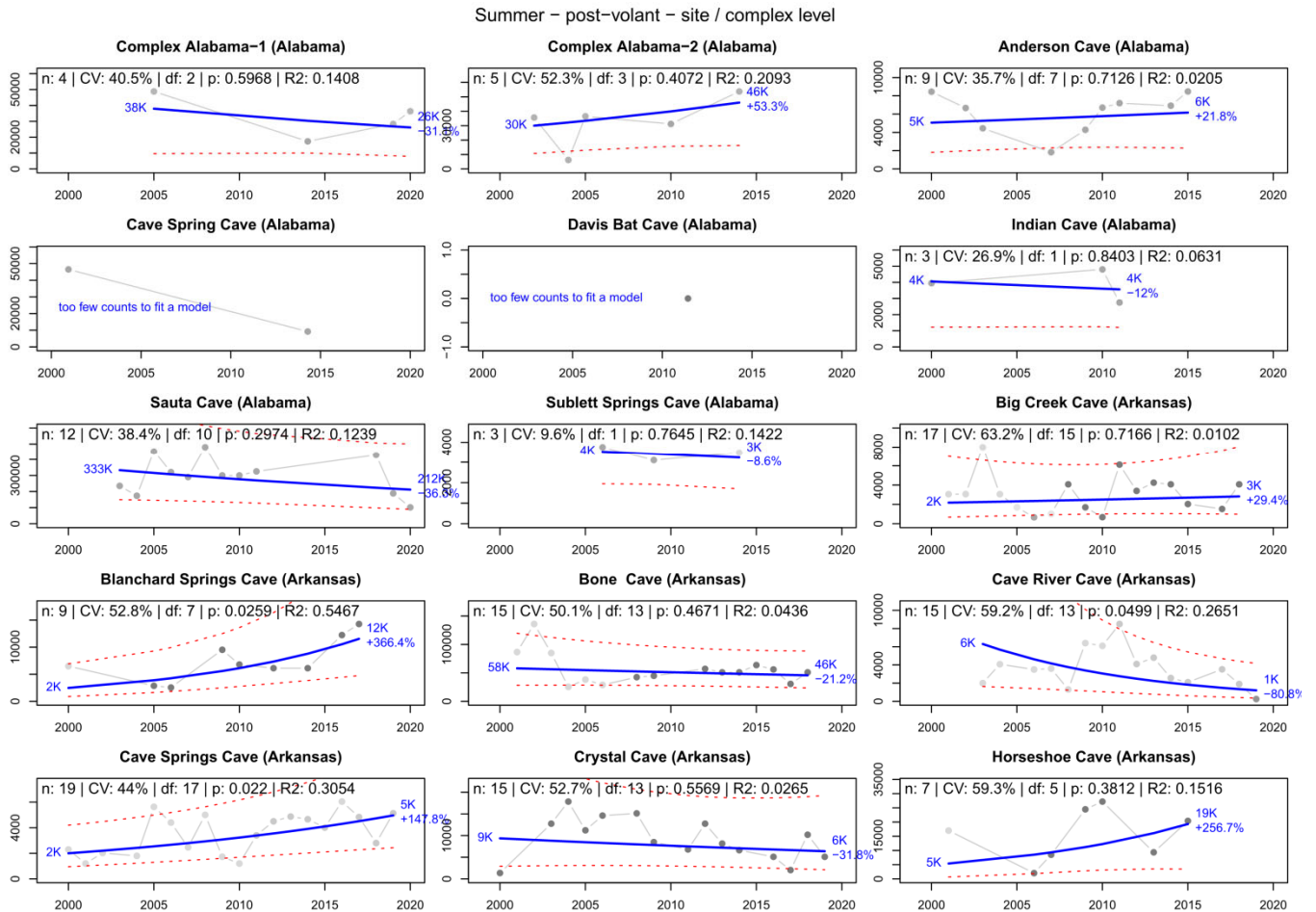
Summer – pre –volant – site / complex level



Summer – pre –volant – site / complex level

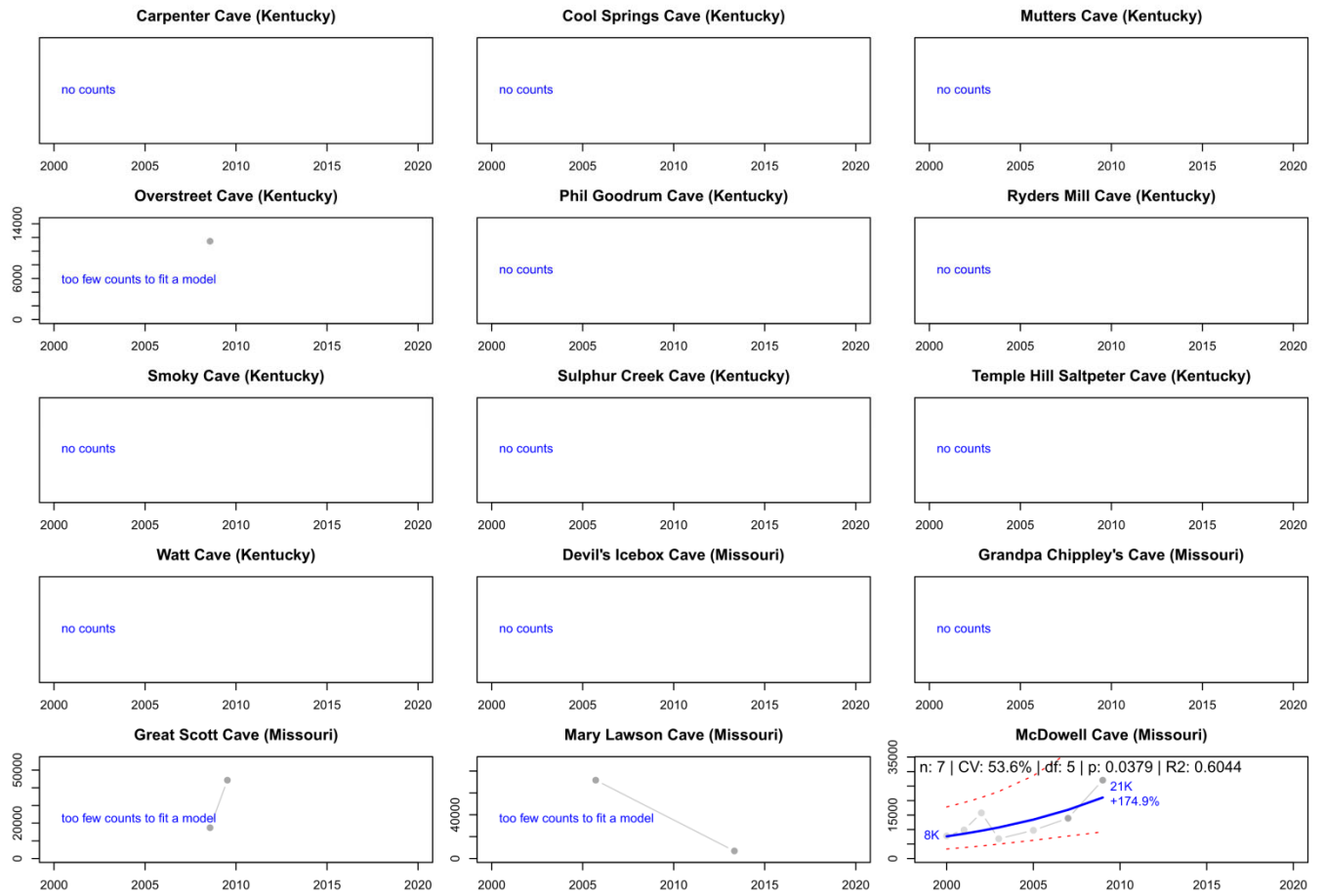


**Figure B8.** Summer post-volant site / complex-scale count data with fitted linear model. Counts are shaded by assigned weights (combined method and within-complex weights), with darker shade indicating greater weight. Blue line: predicted regression line, annotated with predicted start and end population sizes and percent change over modeled period; red dashed lines: 95% confidence intervals of predicted values; n: number of data points; CV: coefficient of variation; p: *p*-value of test for presence of trend in predicted values.

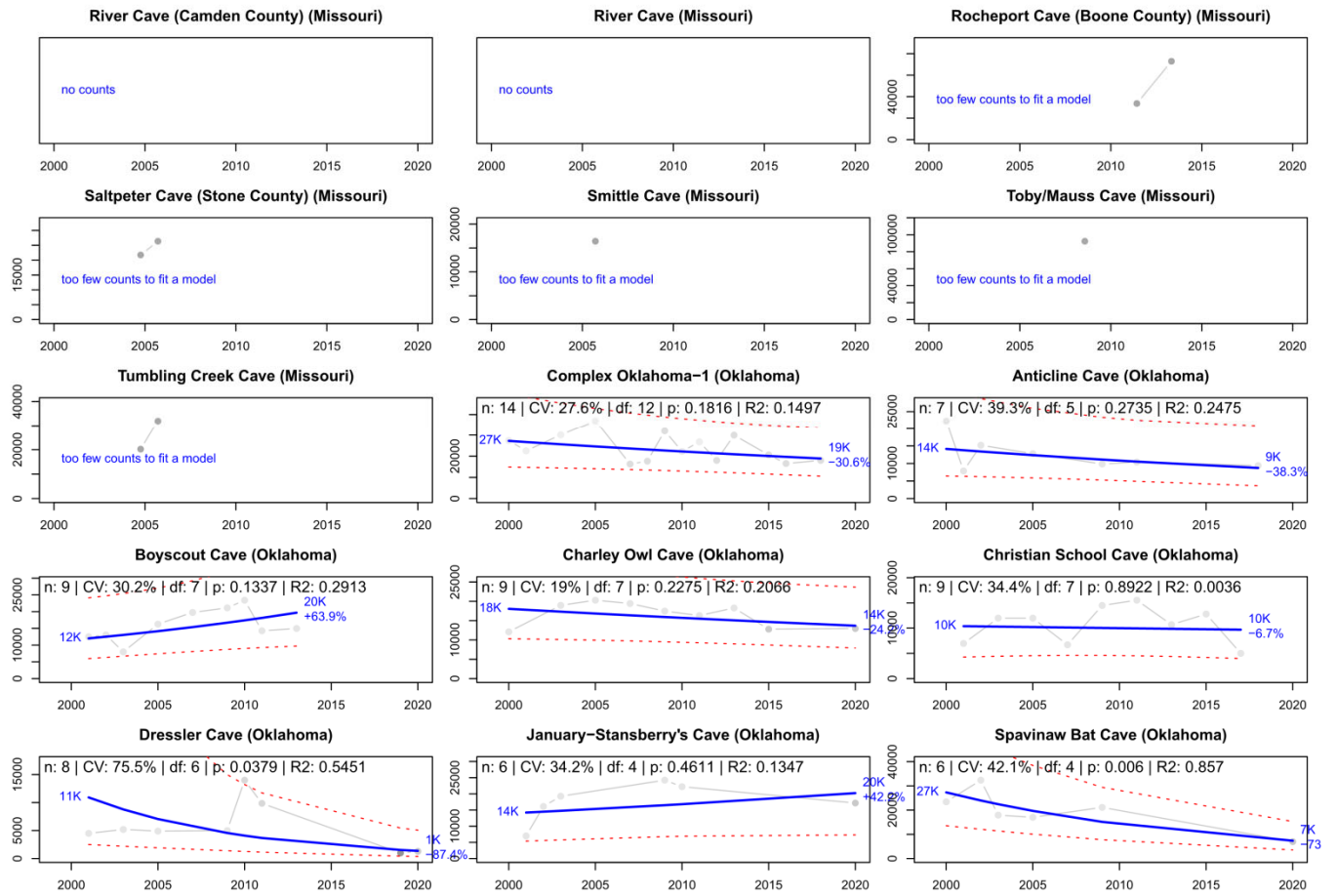




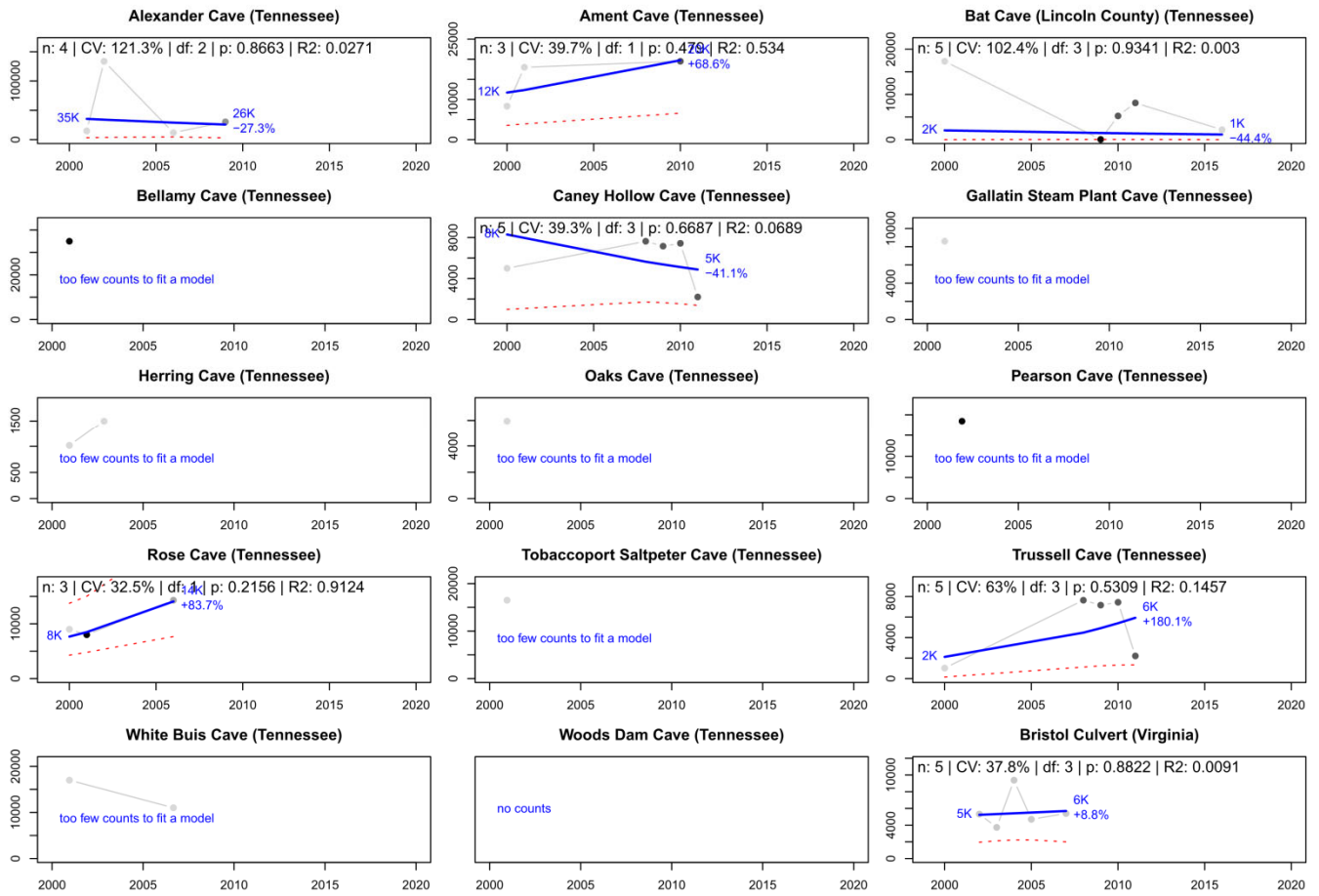
Summer – post-volant – site / complex level



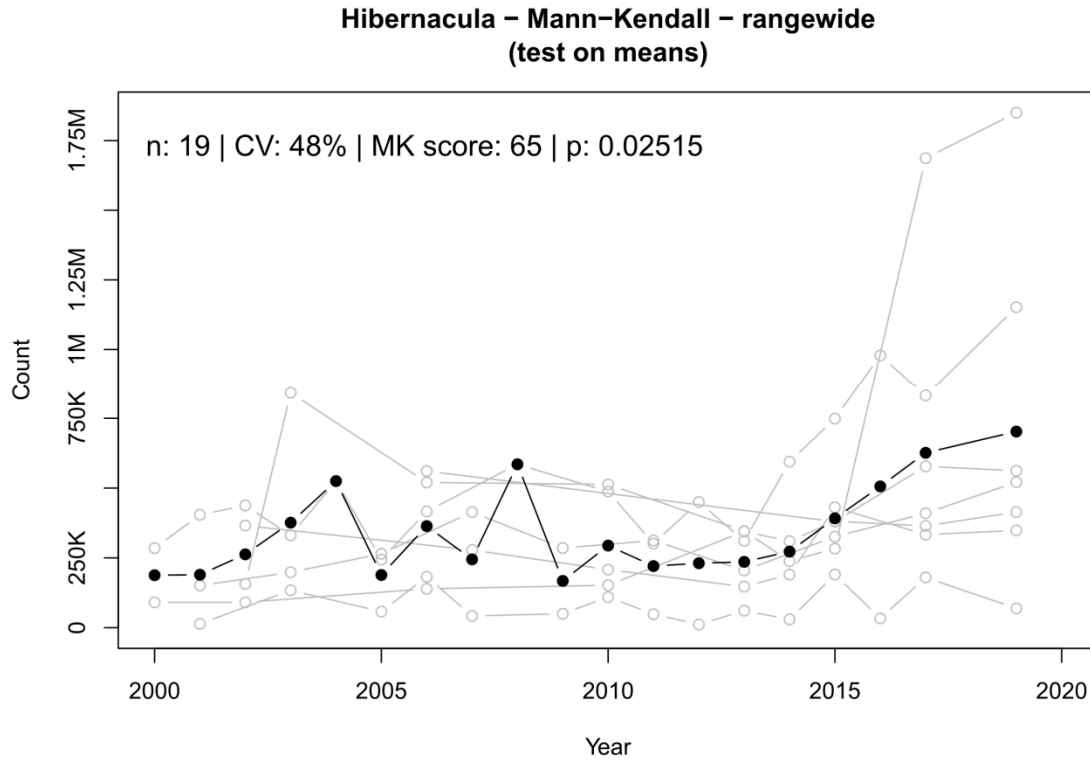
Summer – post-volant – site / complex level



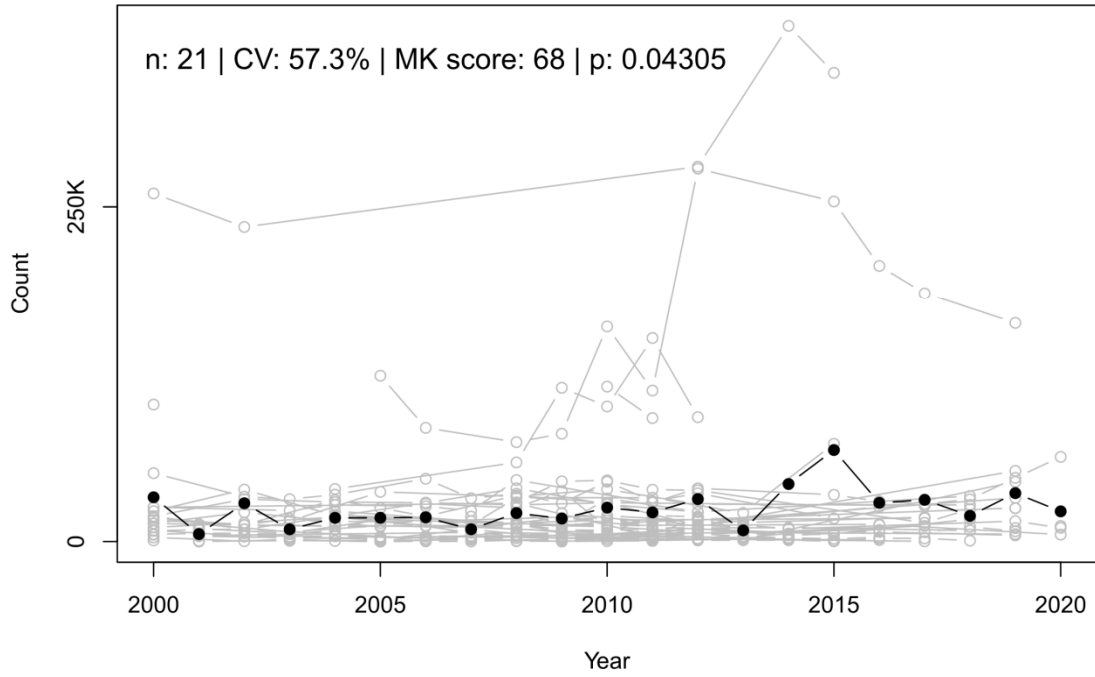
Summer – post-volant – site / complex level



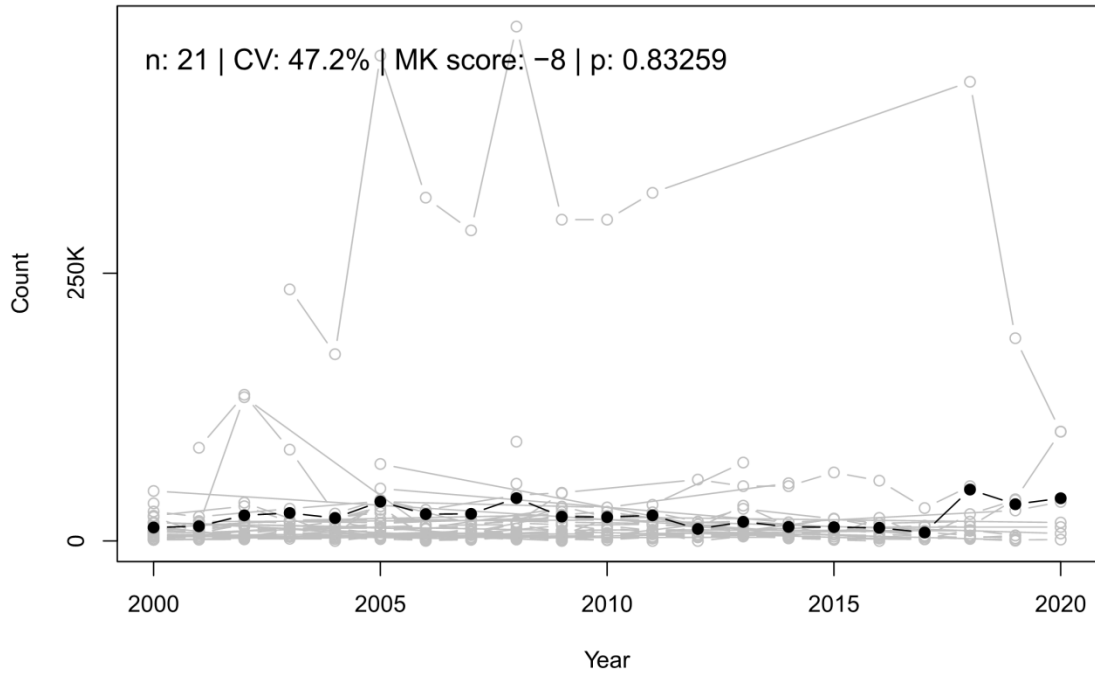
**Figure B9.** Rangewide count data with annual means and Mann-Kendall test results, for hibernacula, pre-volant and post-volant period. Gray series: individual record series at this scale; dark series: annual means; n: number of data points in mean series; CV: coefficient of variation; MK score. Mann-Kendall *S*-statistic; *p*: *p*-value of test for presence of trend based on MK score.



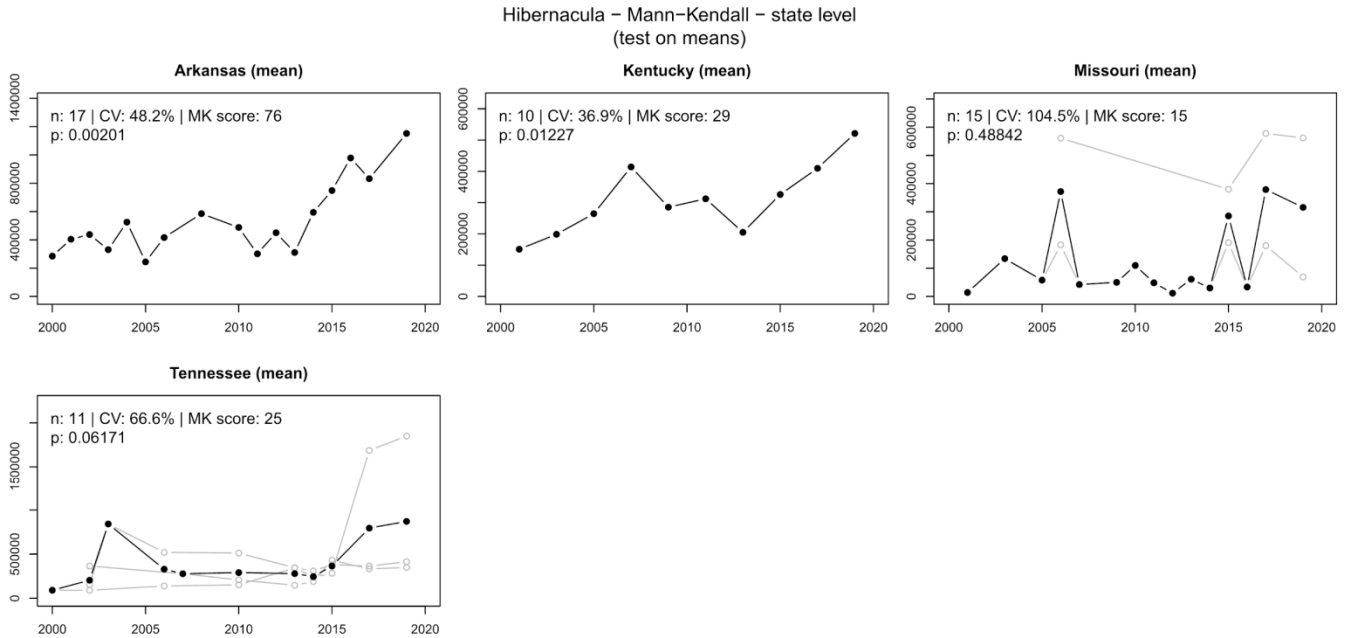
**Summer – pre-volant – Mann-Kendall – rangewide  
(test on means)**



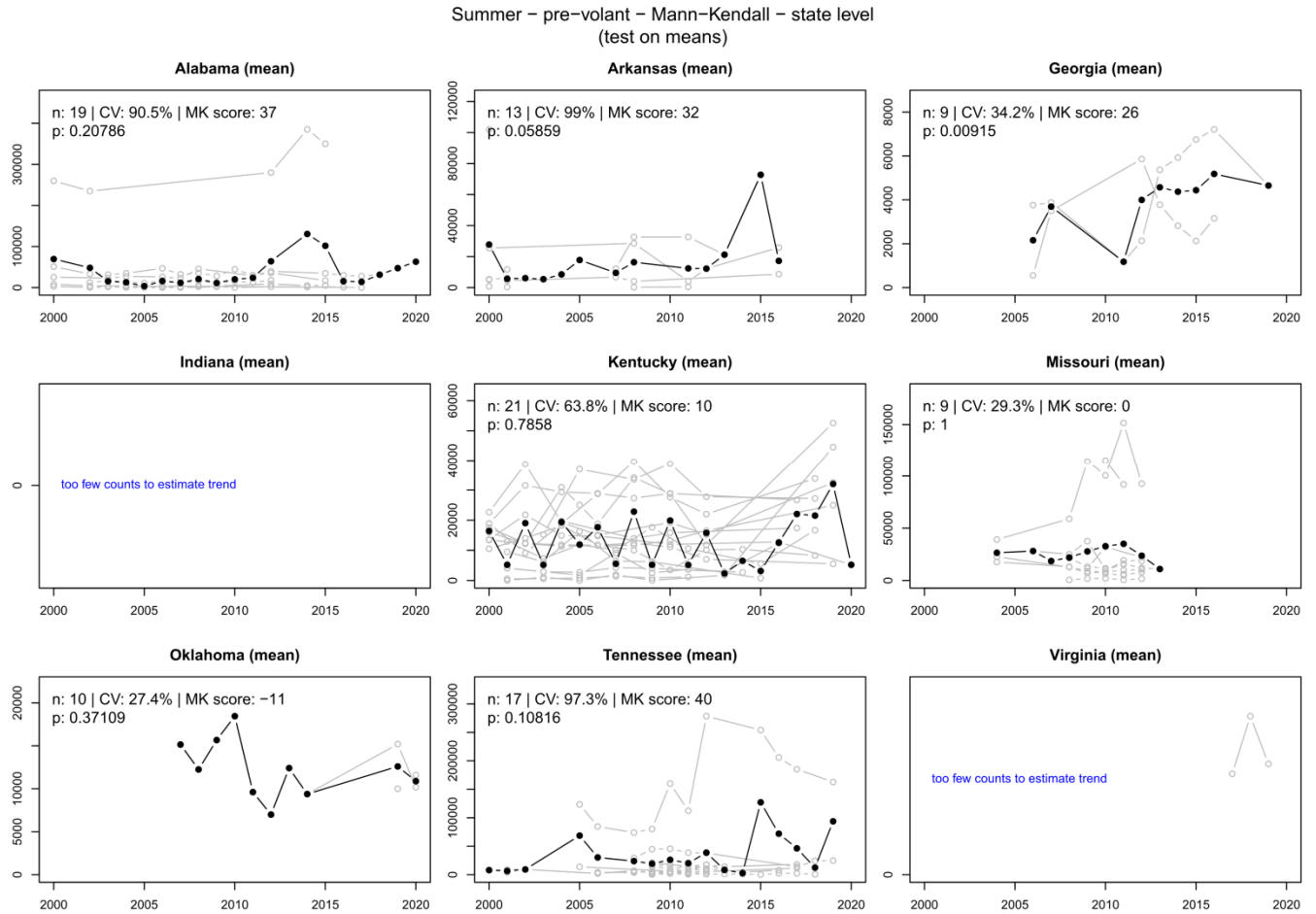
**Summer – post-volant – Mann-Kendall – rangewide  
(test on means)**



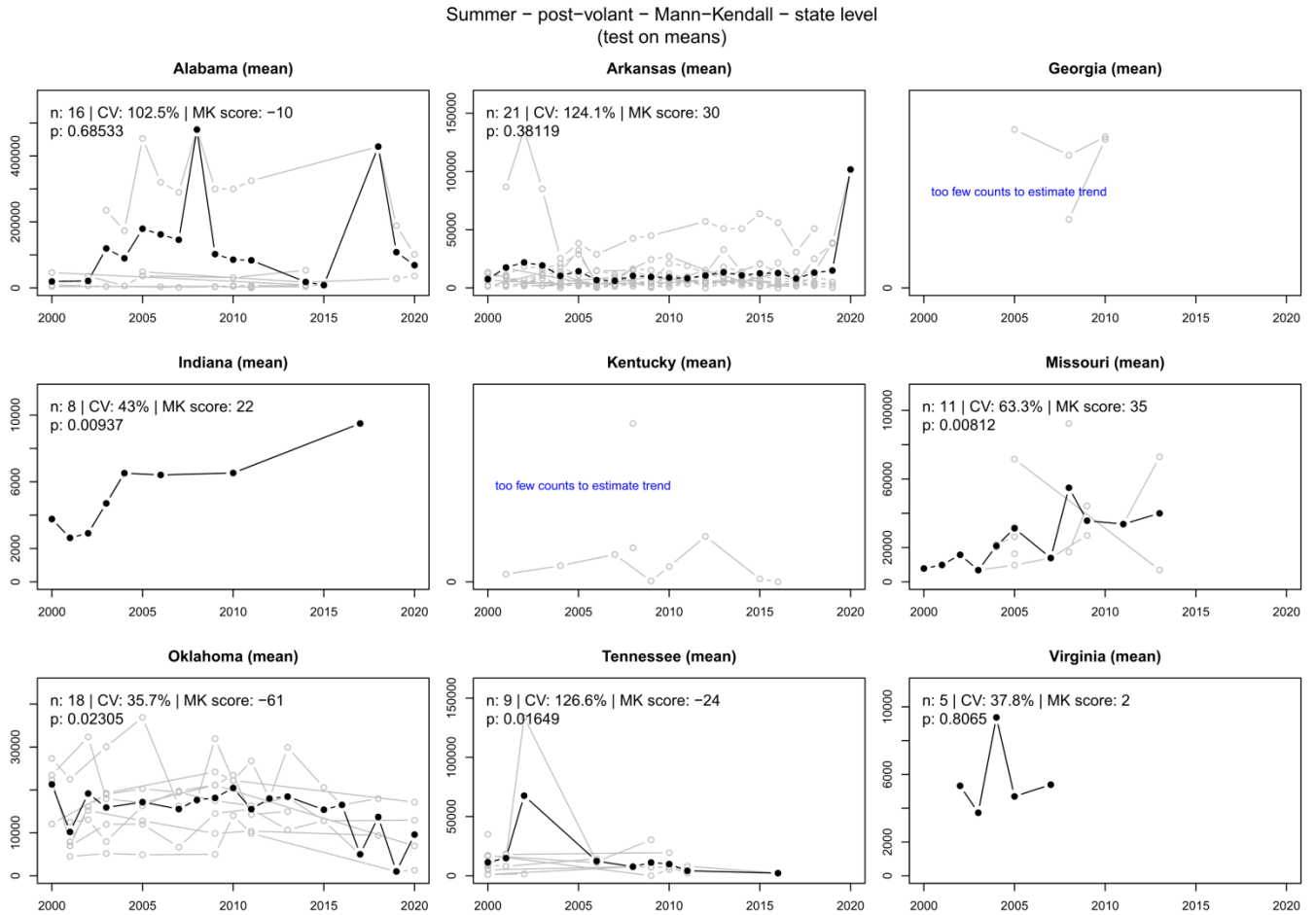
**Figure B10.** Hibernacula state-scale count data with annual means and Mann-Kendall test results, for hibernacula, pre-volant and post-volant period. Gray series: individual record series at this scale; dark series: annual means; n: number of data points in mean series; CV: coefficient of variation; MK score. Mann-Kendall *S*-statistic; *p*: *p*-value of test for presence of trend based on MK score.



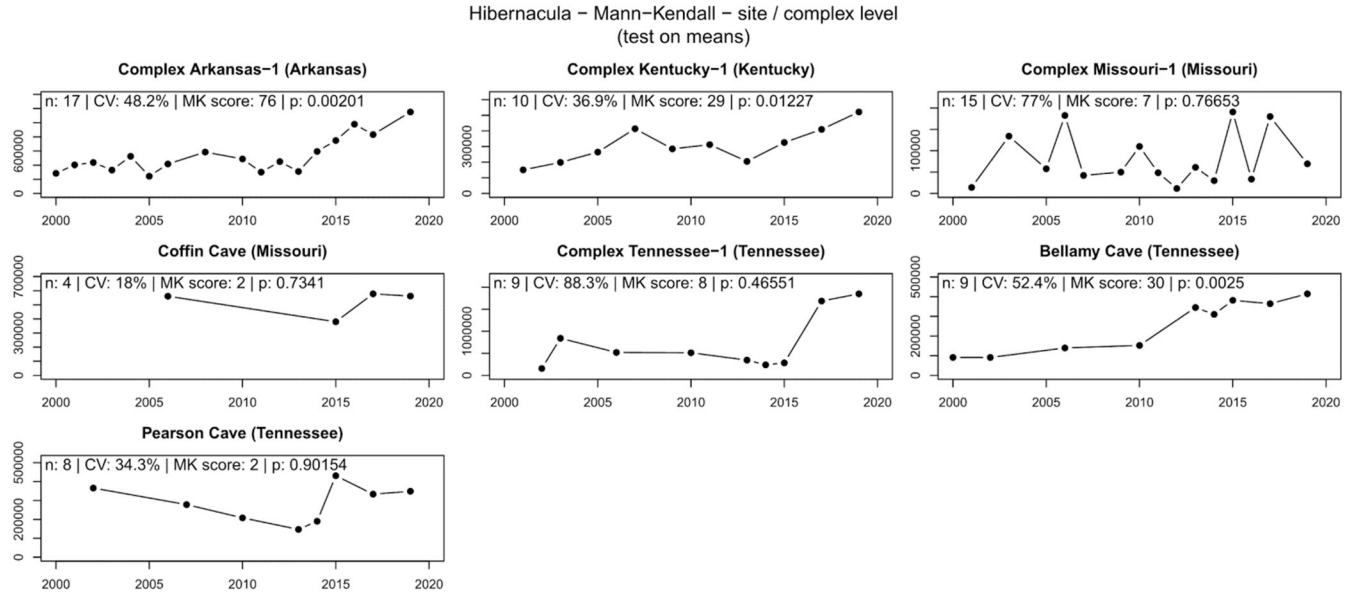
**Figure B11.** Summer pre-volant state-scale count data with annual means and Mann-Kendall test results, for hibernacula, pre-volant and post-volant period. Gray series: individual record series at this scale; dark series: annual means; n: number of data points in mean series; CV: coefficient of variation; MK score. Mann-Kendall  $S$ -statistic;  $p$ :  $p$ -value of test for presence of trend based on MK score.



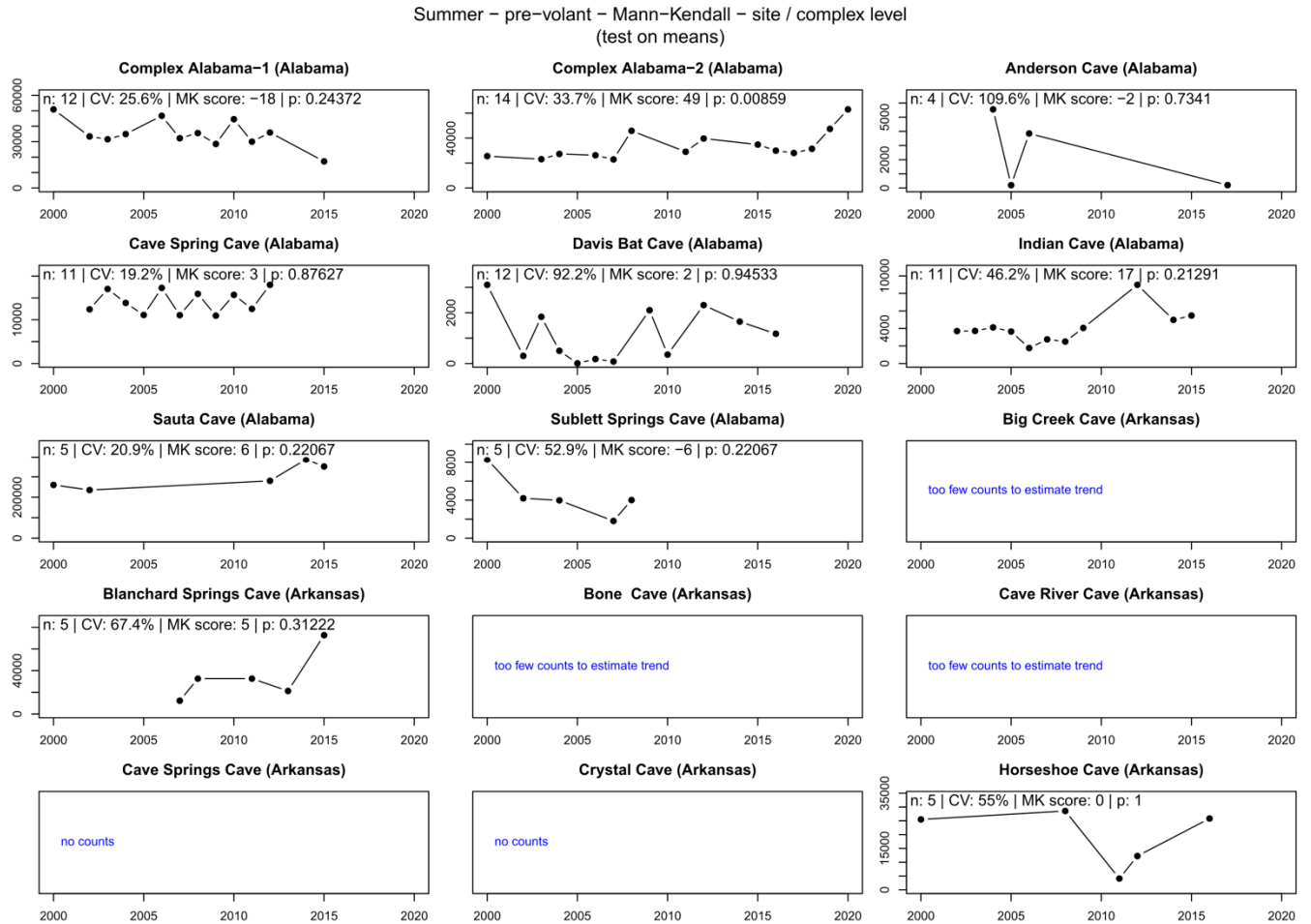
**Figure B12.** Summer post-volant state-scale count data with annual means and Mann-Kendall test results, for hibernacula, pre-volant and post-volant period. Gray series: individual record series at this scale; dark series: annual means; n: number of data points in mean series; CV: coefficient of variation; MK score. Mann-Kendall  $S$ -statistic;  $p$ :  $p$ -value of test for presence of trend based on MK score.



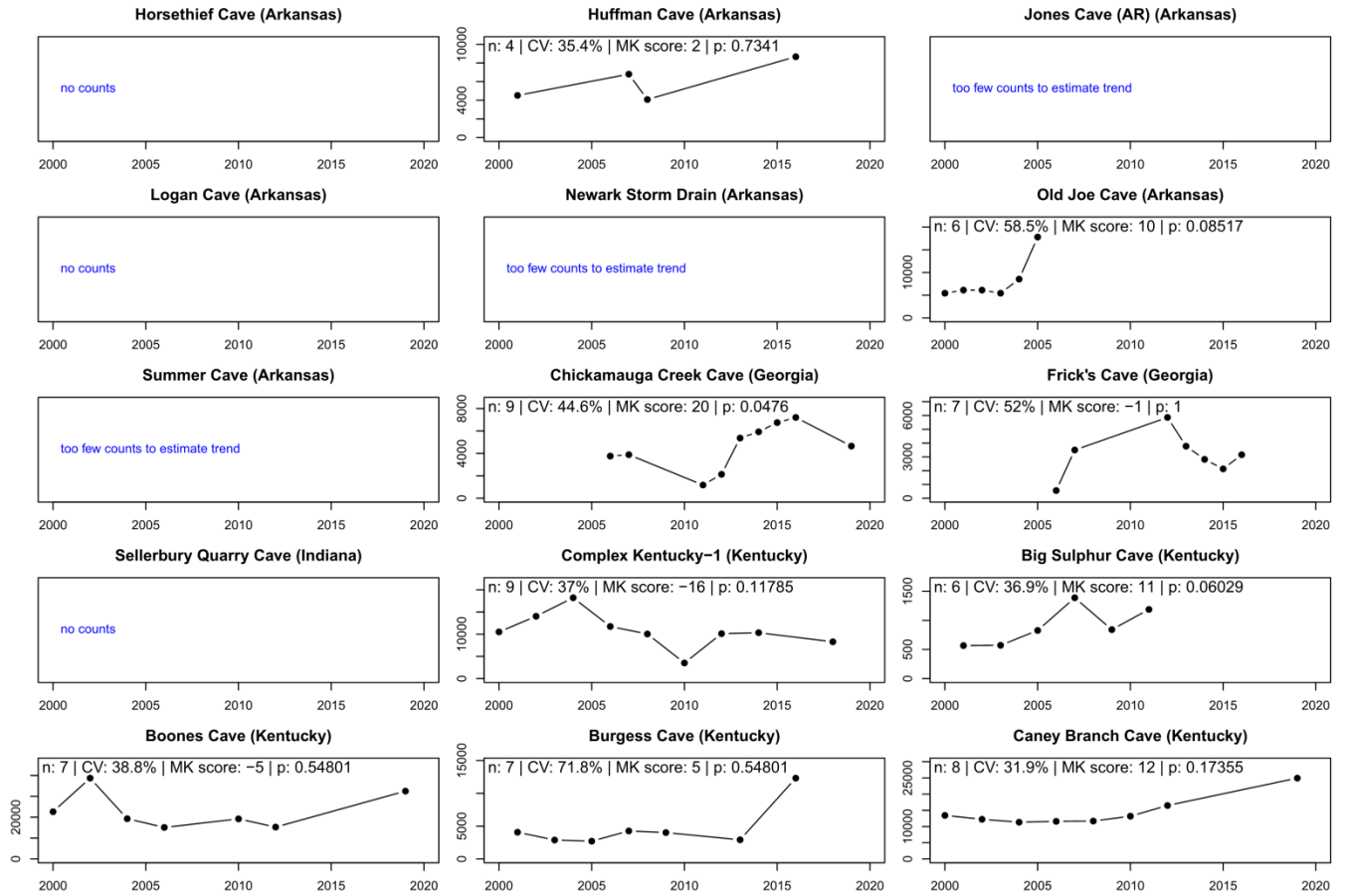
**Figure B13.** Hibernacula complex / site scale count data with annual means and Mann-Kendall test results, for hibernacula, pre-volant and post-volant period. The test is applied to a single data series at this scale. n: number of data points in mean series; CV: coefficient of variation; MK score. Mann-Kendall *S*-statistic; p: *p*-value of test for presence of trend based on MK score.



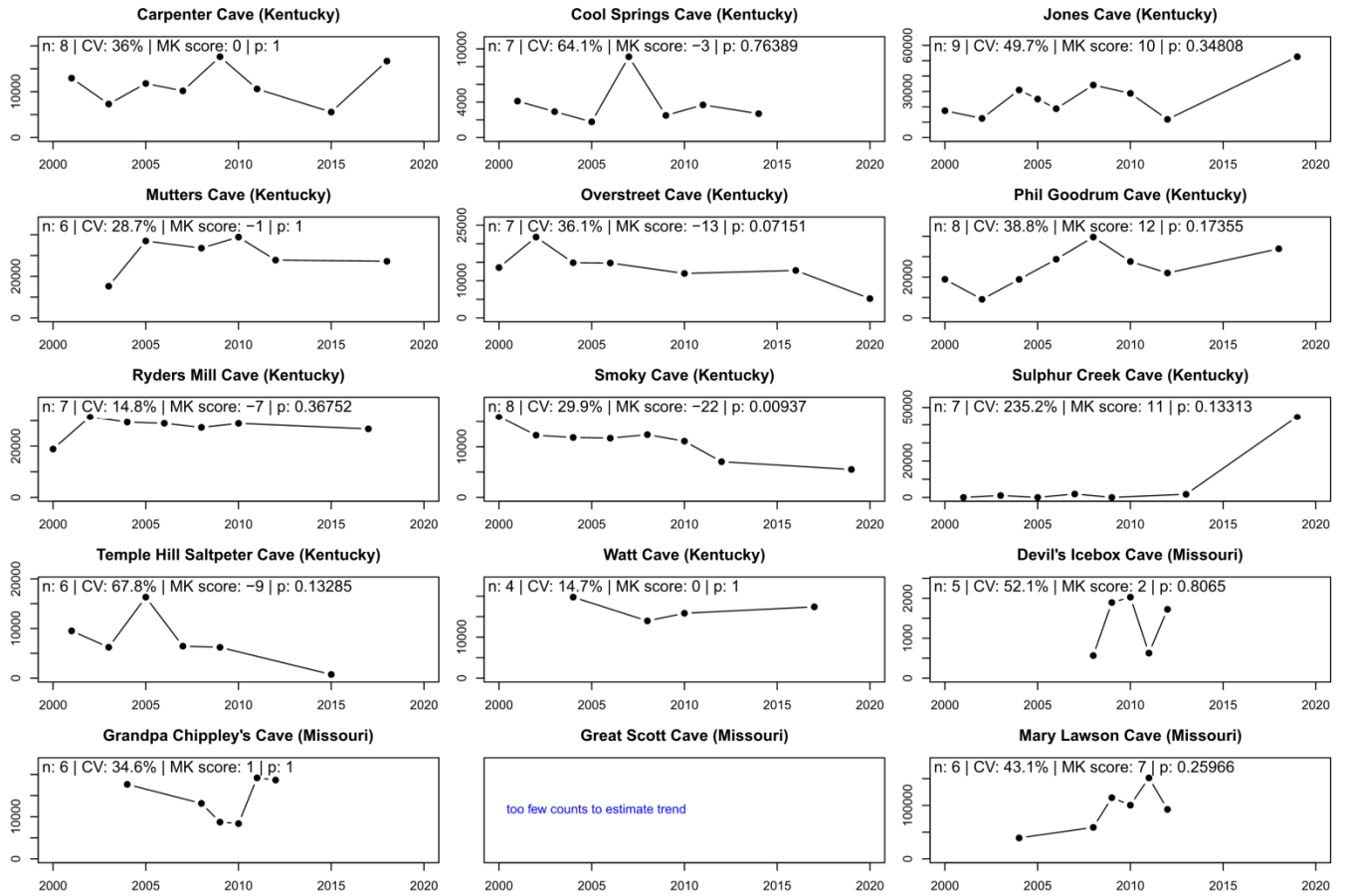
**Figure B14.** Summer pre-volant complex / site scale count data with annual means and Mann-Kendall test results, for hibernacula, pre-volant and post-volant period. The test is applied to a single data series at this scale. n: number of data points in mean series; CV: coefficient of variation; MK score. Mann-Kendall *S*-statistic; p: *p*-value of test for presence of trend based on MK score.



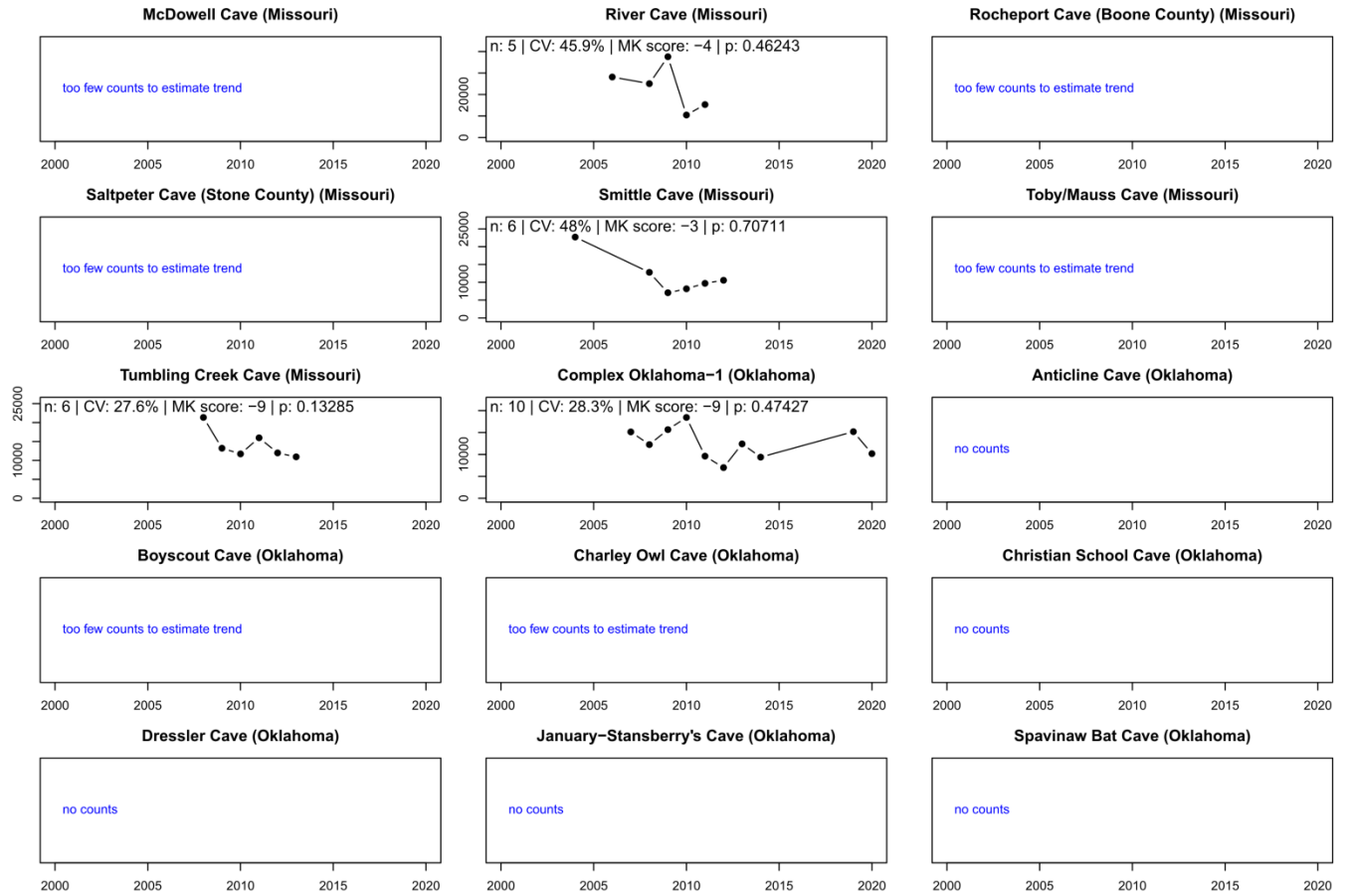
Summer - pre-volant - Mann-Kendall - site / complex level  
(test on means)



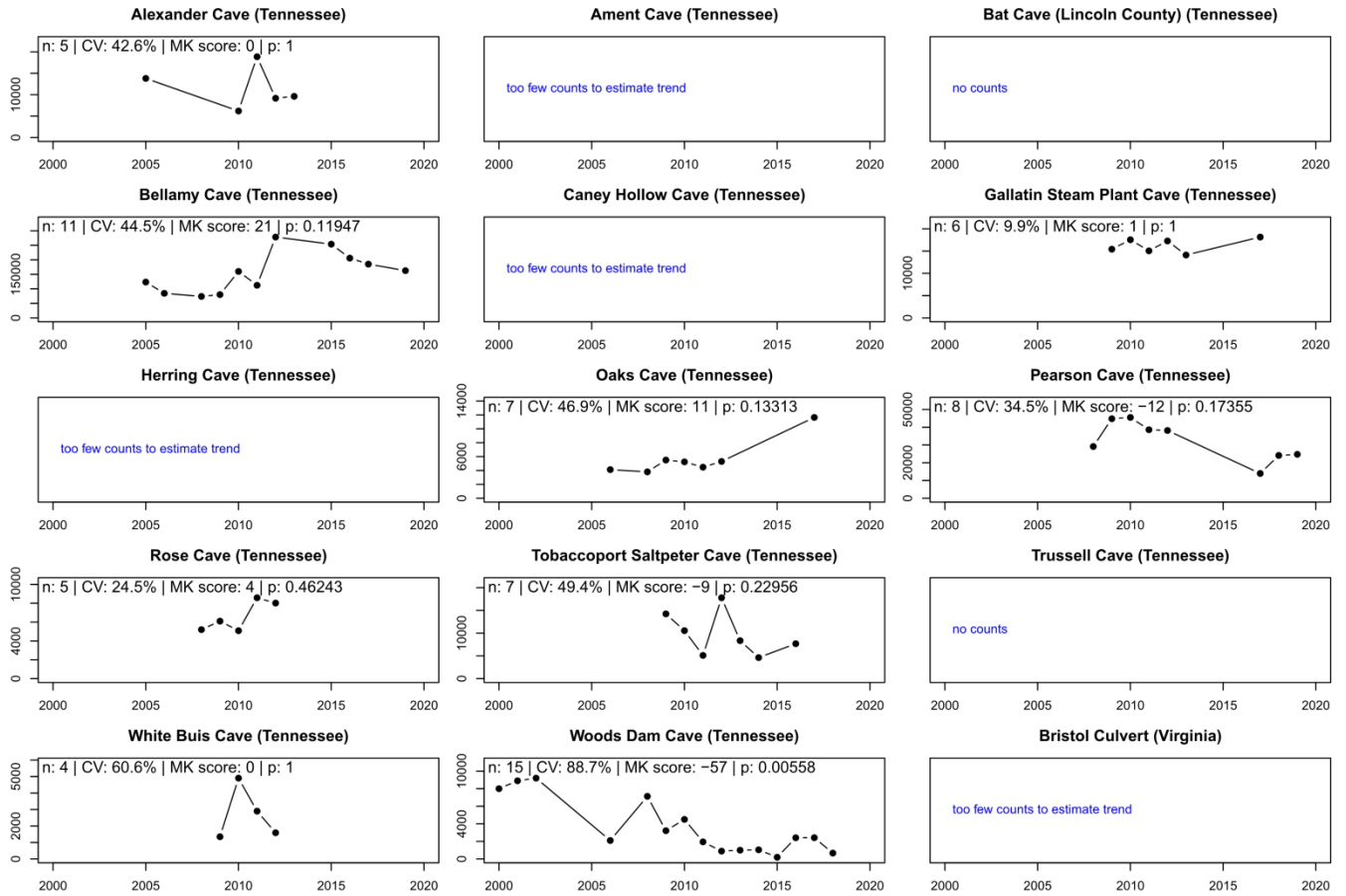
Summer - pre-volant - Mann-Kendall - site / complex level  
(test on means)



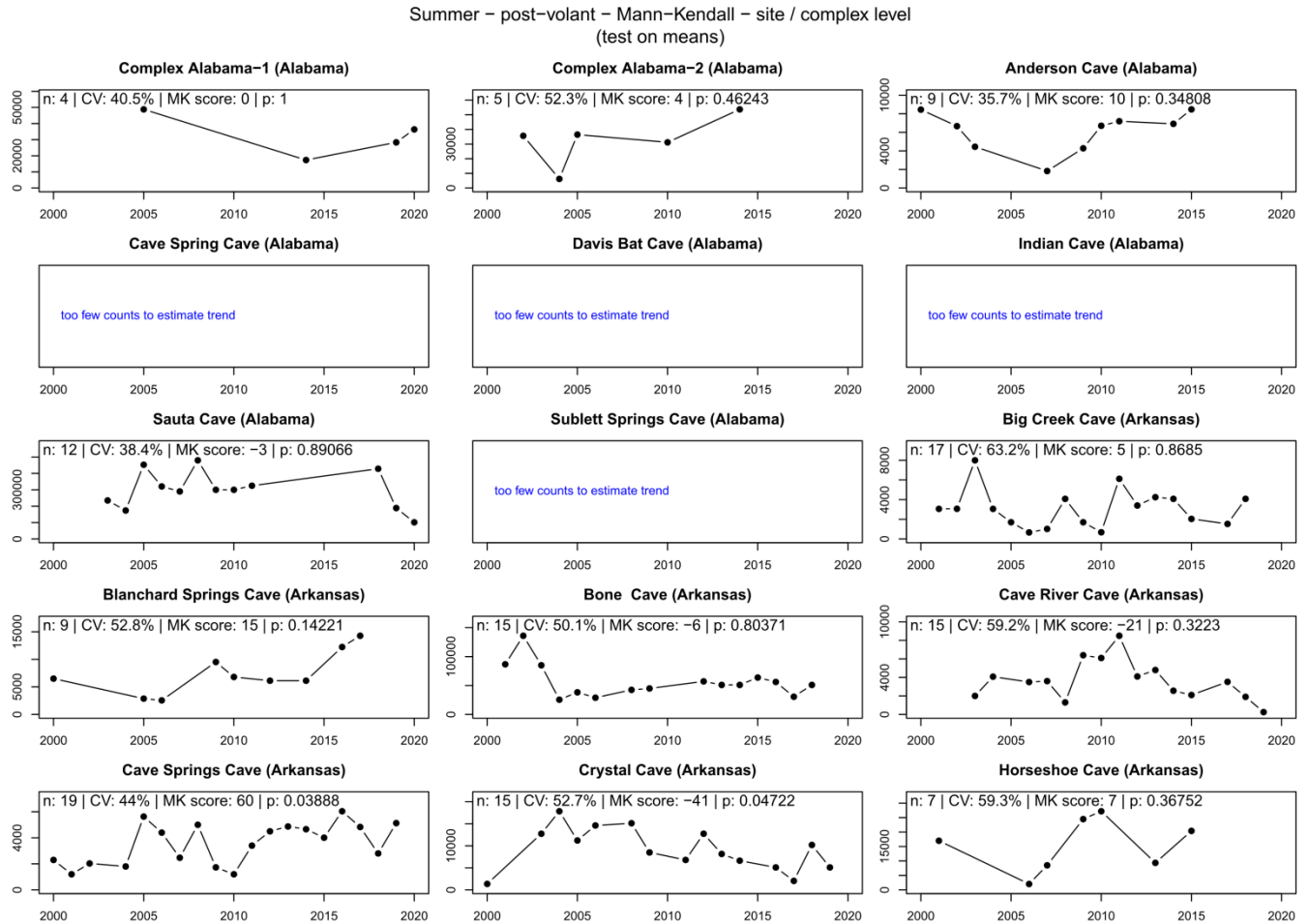
Summer - pre-volant - Mann-Kendall - site / complex level  
(test on means)



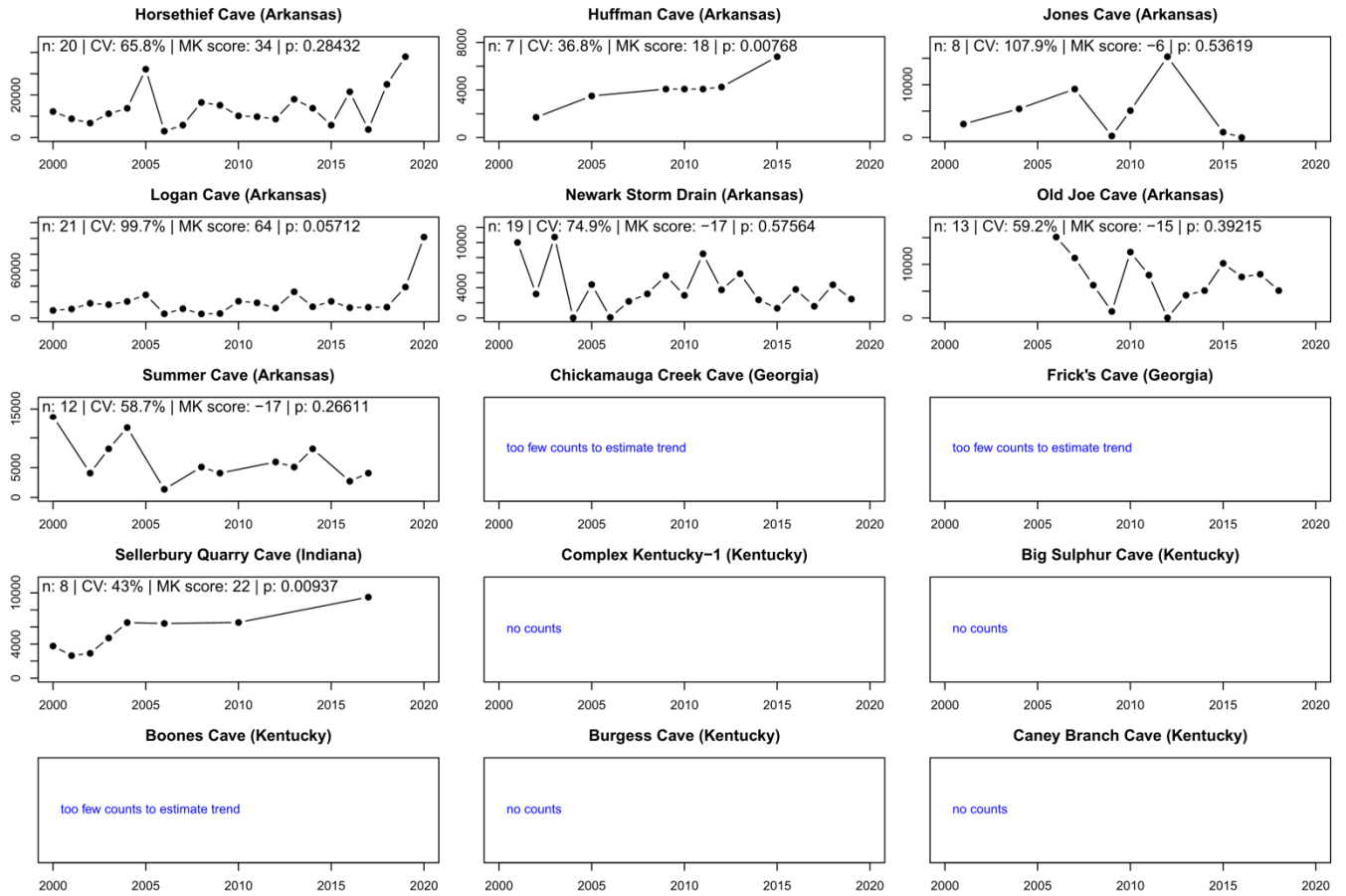
Summer - pre-volant - Mann-Kendall - site / complex level  
(test on means)



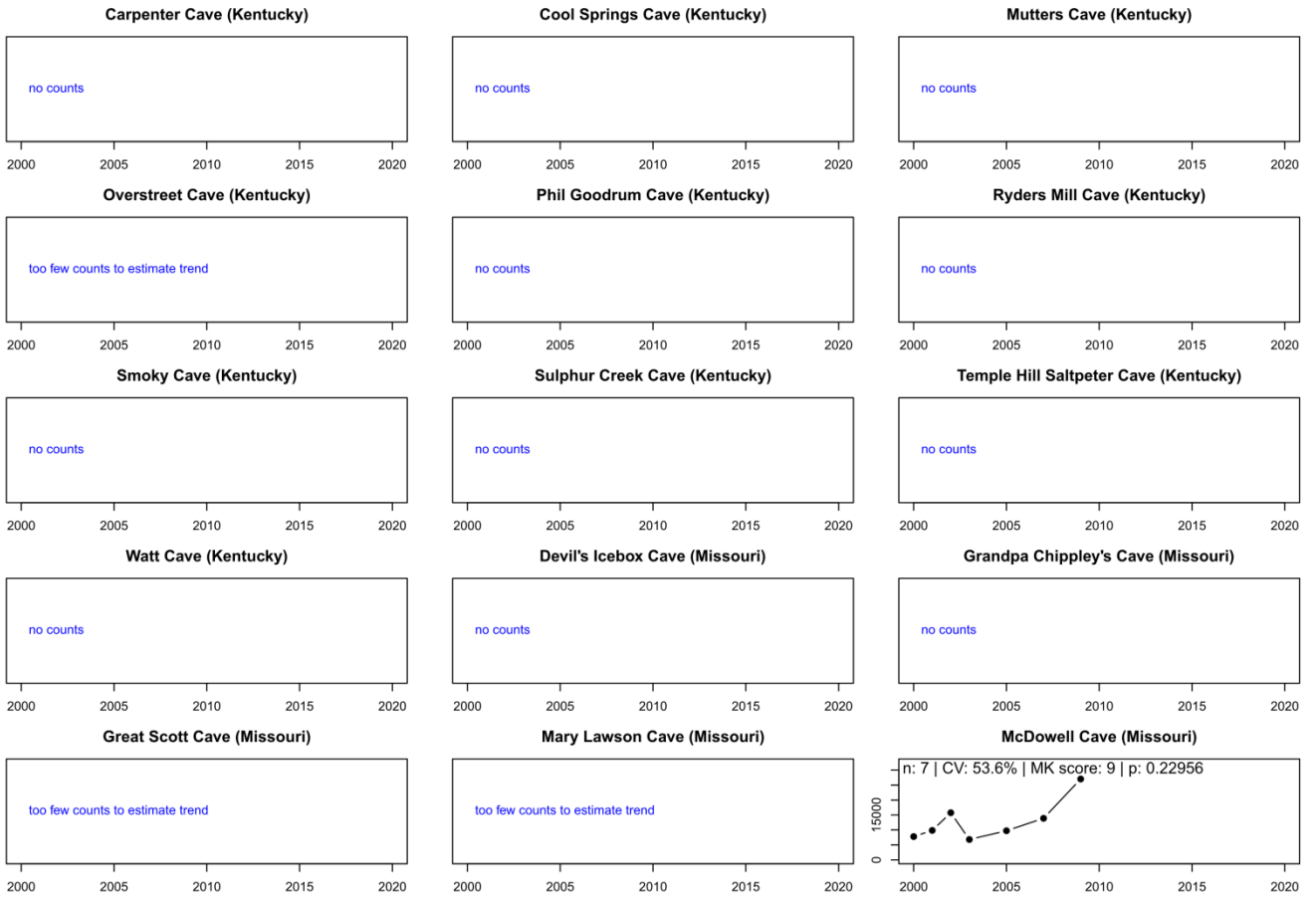
**Figure B15.** Summer post-volant complex / site scale count data with annual means and Mann-Kendall test results, for hibernacula, pre-volant and post-volant period. The test is applied to a single data series at this scale. n: number of data points in mean series; CV: coefficient of variation; MK score. Mann-Kendall *S*-statistic; p: *p*-value of test for presence of trend based on MK score.



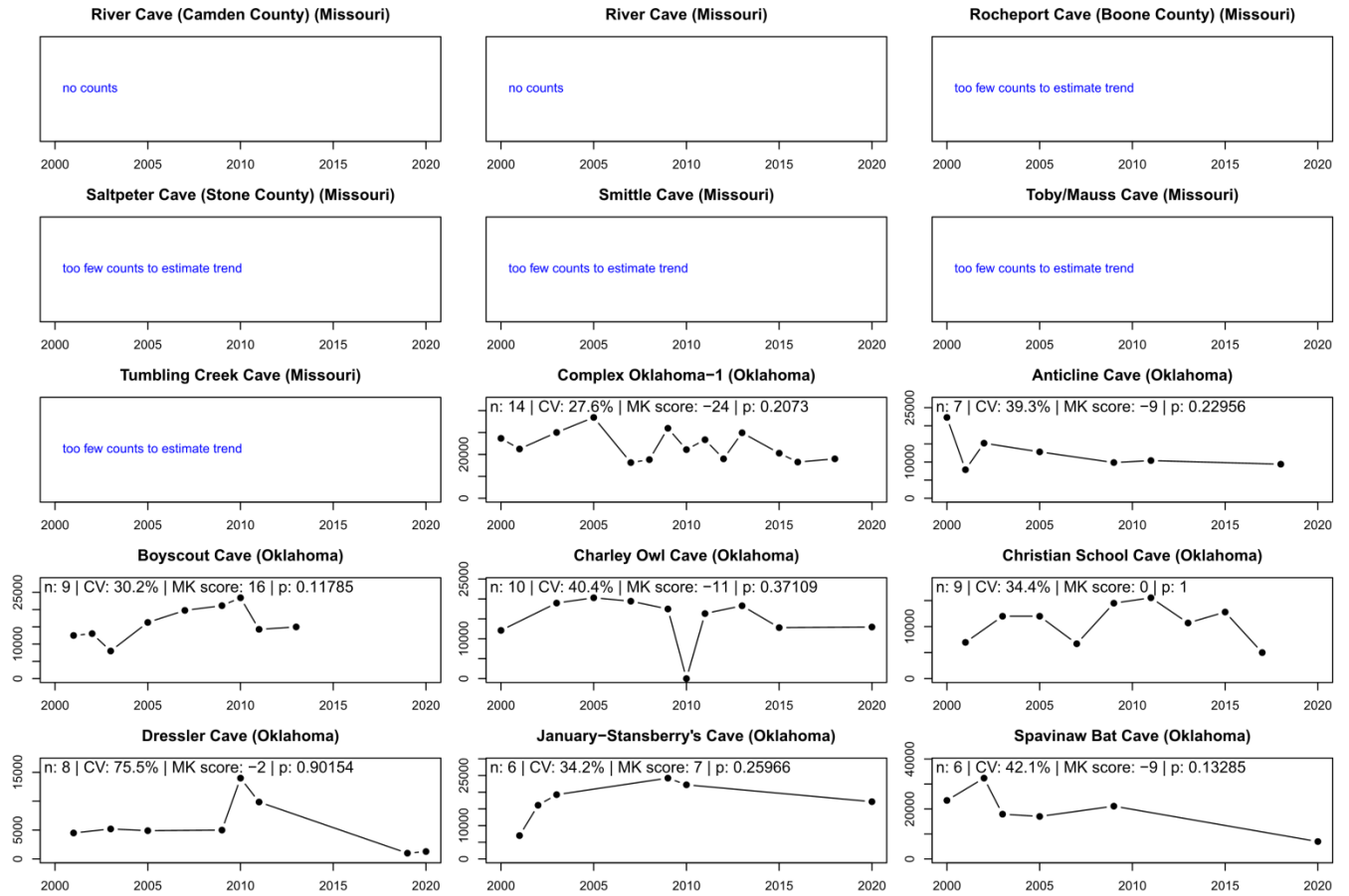
Summer - post-volant - Mann-Kendall - site / complex level  
(test on means)



Summer – post-volant – Mann-Kendall – site / complex level  
(test on means)



Summer - post-volant - Mann-Kendall - site / complex level  
(test on means)



Summer - post-volant - Mann-Kendall - site / complex level  
(test on means)

