Bats Use of Bridges and Culverts

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16. Abstract

Bats are found on every continent except Antarctica and play a crucial role in our ecosystems from pollination to pest control to seed dispersal. Although bats use natural roosts such as trees and caves, many species also use anthropogenic roosts such as buildings and transportation structures. Because of this, a growing number of transportation departments are integrating bat management strategies into structure maintenance schedules. The objectives of this document were to compile what is known about how bats use transportation structures (specifically bridges and culverts), determine what technologies are available for surveying these structures for bats, and report on available methods for removing bats or deterrents for discouraging use during construction and repairs. Here we include a review of literature from journal articles, departments of transportation manuals, federal documents, questionnaires, conference materials, white papers, and gray literature. The literature review revealed that most of what we know about bat use of bridges and culverts comes from states in the western part of the U.S. There is a good understanding of structure material, size, and surrounding habitat that is favorable for western bats, and structure roosting information on western bat species use has been well documented. However, there is not a good understanding and there is a lot less information about how bats use these structures in the eastern states. There are an increasing number of practices, data collection forms, and electronic resources used for bat surveys at transportation structures as this topic of interest has gained popularity in recent years. The use of these resources and continued efforts to survey transportation structures will provide comparable data to the western states. With more federally threatened and endangered bat species in the east than in the west, and several species under status review for listing, the collection of these data are more important than ever.

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Bats Use of Bridges and Culverts

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ABSTRACT

Bats are found on every continent except Antarctica and play a crucial role in our ecosystems from pollination to pest control to seed dispersal. Although bats use natural roosts such as trees and caves, many species also use anthropogenic roosts such as buildings and transportation structures. Because of this, a growing number of transportation departments are integrating bat management strategies into structure maintenance schedules. The objectives of this document were to compile what is known about how bats use transportation structures (specifically bridges and culverts), determine what technologies are available for surveying these structures for bats, and report on available methods for removing bats or deterrents for discouraging use during construction and repairs. Here we include a review of literature from journal articles, departments of transportation manuals, federal documents, questionnaires, conference materials, white papers, and gray literature. The literature review revealed that most of what we know about bat use of bridges and culverts comes from states in the western part of the U.S. There is a good understanding of structure material, size, and surrounding habitat that is favorable for western bats, and structure roosting information on western bat species use has been well documented. However, there is not a good understanding and there is a lot less information about how bats use these structures in the eastern states. There are an increasing number of practices, data collection forms, and electronic resources used for bat surveys at transportation structures as this topic of interest has gained popularity in recent years. The use of these resources and continued efforts to survey transportation structures will provide comparable data to the western states. With more federally threatened and endangered bat species in the east than in the west, and several species under status review for listing, the collection of these data are more important than ever.

EXECUTIVE SUMMARY

Bats use natural roosts such as trees and caves, but many species also use anthropogenic roosts such as buildings and transportation structures. Because of this, a growing number of transportation departments are integrating bat management techniques into structure maintenance schedules. The objectives of this document were to compile what is known about how bats use transportation structures (specifically bridges and culverts), determine what technologies are available for surveying these structures for bats, and report on available methods for removing bats or using deterrents to discourage use during construction and repairs. To accomplish this task, a thorough literature search was conducted using journal articles, transportation documents, media stories, and answers to questionnaires sent to state and federal agencies in the United States (U.S.). Although we report on all species found, the focus of the study was on five species that have some federal status: endangered Indiana bat (*Myotis sodalis*), endangered gray bat (*Myotis grisescens*), threatened northern long-eared bat (*Myotis septentrionalis*)[1], tricolored bat (*Perimyotis subflavus*) that is proposed endangered, and little brown bat (*Myotis lucifugus*) that is under review for listing.

Of the studies that reported the proportion of bridges used, 13.8% of the 8,648 structures surveyed across 21 studies in the U.S. showed signs of bat use. At least 25 bat species have been documented using transportation structures in the U.S., including species that are federally threatened or endangered. Most of the published literature reviewed focused on locating bats in bridges and culverts and identifying the characteristics of preferred structures and surrounding habitat. Though bats have been documented using metal and wooden structures, it is overwhelmingly evident that bats prefer concrete bridges and culverts, likely for the material's thermal properties and frictional properties for ease of roosting. Distance to water and suitable foraging habitat also seem to be important, though this may be based on habitat availability. Bats are mostly found on older bridges with expansion joints, hinges, and weep holes or areas of deterioration that create crevices or cave-like spaces. It was previously thought that bats preferred culverts between 5-10 feet tall, but more recent data suggest that bats will use culverts as short as 2 feet tall. Transportation structures can be used year-round, during the day and for short periods at night. Multiple species use transportation structures as maternity roosts, transitional roosts during migration, and in southern states, a few species use structures as hibernacula.

Researchers and agency personnel use common tools to find bats in structures such as a spotlight and binoculars. For difficult to access sections, a borescope camera that records videos and images can be helpful. Another option can be drones fitted with thermal cameras to record areas of the bridge that researchers cannot see and may also be used to aid in emergence counts. Acoustic detectors have been used at bridges and on drones to detect bats, but this technique does not help in estimating colony size or species use. Since bat use can be seasonal or sometimes difficult to detect, some transportation departments are funding research to develop new techniques to assist practitioners in identifying bridges with bat use. In Virginia, artificial intelligence technology has been used to detect bat urine and guano staining on bridges from

[1] Uplisting to endangered expected on 31 March 2023

photographs. In North Carolina, modeling is being used to identify which bridges have the highest probability of use based on bridge characteristics and surrounding habitat.

When bat use has been documented, managing the individuals or colonies during maintenance or replacement of deteriorating structures is important. This can be done with deterrents and/or exclusions. In general, deterrents discourage bats from approaching a structure whereas exclusions are physical barriers in the bats' preferred roosting spots. In most cases and if scheduling allows, maintenance and/or exclusion can be done when the bats are not occupying the structure (e.g., at night or in winter). When this is not possible, there are techniques to exclude bats temporarily or permanently. The most common technique uses one-way doors to allow bats out of the roost but not back in, and then use backer-rod or pool noodles to fill crevices. Once the bats are out of the structure, roosting areas can be permanently sealed if desired. If more time sensitive repairs need to be made on a structure with a bat colony, acoustic deterrents currently being used at wind energy facilities to keep bats away from turbines are the most promising technique. Although there were only few studies testing acoustic deterrents at bridges, they all suggested that this technique has merit and requires further study.

In the western U.S. where bats in transportation structures have been studied for longer and for more species than in the east, common mitigation strategies include providing alternate roosting structures, either built into the bridge structure, added to the structure, or free-standing from the structure. The least beneficial method is replacing loss of bridge or culvert roost habitat with a free-standing artificial roost. In Kentucky, the Kentucky Transportation Cabinet successfully replaced a deteriorating bridge used by the federally endangered gray bat (*Myotis grisescens*) as a maternity roost with a new bridge built with expansion joints sized specifically to bat roost specifications. Recolonization of the new bridge was confirmed the following year by emergence counts.

Transportation departments in the eastern U.S. face additional issues compared to western counterparts because of the documented presence of federally listed bat species roosting on structures. One way to account for impacts to federally listed bats from transportation projects is through Endangered Species Act (ESA), Section 7 consultation which documents loss of habitat and could include avoidance and minimization measures, in-lieu fees, and various mitigation options. As more eastern states find federally listed bats on transportation structures and more bat species continue to be uplisted and added to the endangered species list, some agencies are choosing to go into additional consultation to help streamline projects and account for more species.

ACRONYMS AND ABBREVIATIONS

Caltrans	California Department of Transportation
CBWG	California Bat Working Group
Copperhead	Copperhead Environmental Consulting, Inc.
DBH	diameter at breast height
DOT	Department of Transportation
ESA	Endangered Species Act
FHWA	Federal Highway Administration
GADNR	Georgia Department of Natural Resources
HPS	high powered sodium (light)
IUCN	International Union for Conservation of Nature
KYTC	Kentucky Transportation Cabinet
LED	Light-emitting diode
MoDOT	Missouri Department of Transportation
NCDOT	North Carolina Department of Transportation
ODOT	Ohio Department of Transportation
Pd	*Pseudogymnoascus destructans*
Range-wide BO	Programmatic Biological Opinion for Transportation Projects in the Range of the Indiana Bat and Northern Long-Eared Bat
U.S.	United States
USFWS	United States Fish and Wildlife Service
UV	ultraviolet (light)
VTrans	Vermont Agency of Transportation
WNS	White-nose syndrome

1 INTRODUCTION

Bats are important to healthy ecosystems and provide many ecological services including insect control, pollination, and seed dispersal. As of 2022, there were 1,456 named species of bats in the world. The International Union for Conservation of Nature (IUCN) tracks the range, population size, habitats, and ecology of 1,332 species of bats. Worldwide declines to bats are occurring due to habitat destruction/modification, pesticides and pollution, human development, climate change, and disease. Currently, 24% of the world's bats are listed by the IUCN as critically endangered (n = 23 species), endangered (n = 85 species), vulnerable (n = 113 species), or near threatened (n = 91 species). In the United States there are 48 species of bats, 10 of which are listed by IUCN as endangered (n = 3 species), vulnerable (n = 3 species), or near threatened (n = 4 species). Several of these species were in decline due to habitat destruction or intentional killing, but more recently, additional bat populations are in decline due to white-nose syndrome (WNS), a high-mortality disease caused by the cold-loving fungus *Pseudogymnoascus destructans* (Pd) that was accidentally introduced from Europe in 2006. Stressors such as WNS and human population growth have caused many animals, including bats, to adapt or perish. For bats, the loss of natural habitats means adapting roosting behaviors to include the use of anthropogenic structures such bridges and culverts.

Bats are routinely found roosting in transportation structures around the world, particularly in the continental western United States (Figure 1) where this phenomenon has been studied longer and for more bat species. Interest in studying this topic in the eastern United States has increased only in the last several years. As more bridges and culverts are surveyed for bats, it is becoming evident that these structures are used extensively year-round in some cases and seasonally in others. In addition, federally threatened or endangered species, as well as those proposed or under review for listing, have been documented using these anthropogenic roosts. To compound this issue, there are over 40,000 structurally deficient bridges in need of repair in the U.S. Although departments of transportation (DOTs) generally avoid impacts to bats during repairs or replacement of bridges and culverts, the use of these structures by federally listed species poses another level of protection and needed understanding.

Missouri Department of Transportation (MoDOT) contracted Copperhead Environmental Consulting, Inc. (Copperhead) to summarize what is known about bats' use of transportation structures and to investigate current and emerging technologies used to conduct efficient surveys of structures. In addition, MoDOT is interested in learning about deterrents, relocation, or other methods for temporarily keeping bats off structures during alterations such as construction, repair, or removal. Although all bats are of interest, this review focuses on the five species of bats with some level of federal status (Table 1).

To accomplish this task, we conducted research using sources primarily from the U.S., but a few European studies are also referenced. We compiled journal articles, DOT documents, media stories, and answers to questionnaires created by Copperhead and sent to state and federal agencies throughout the U.S.

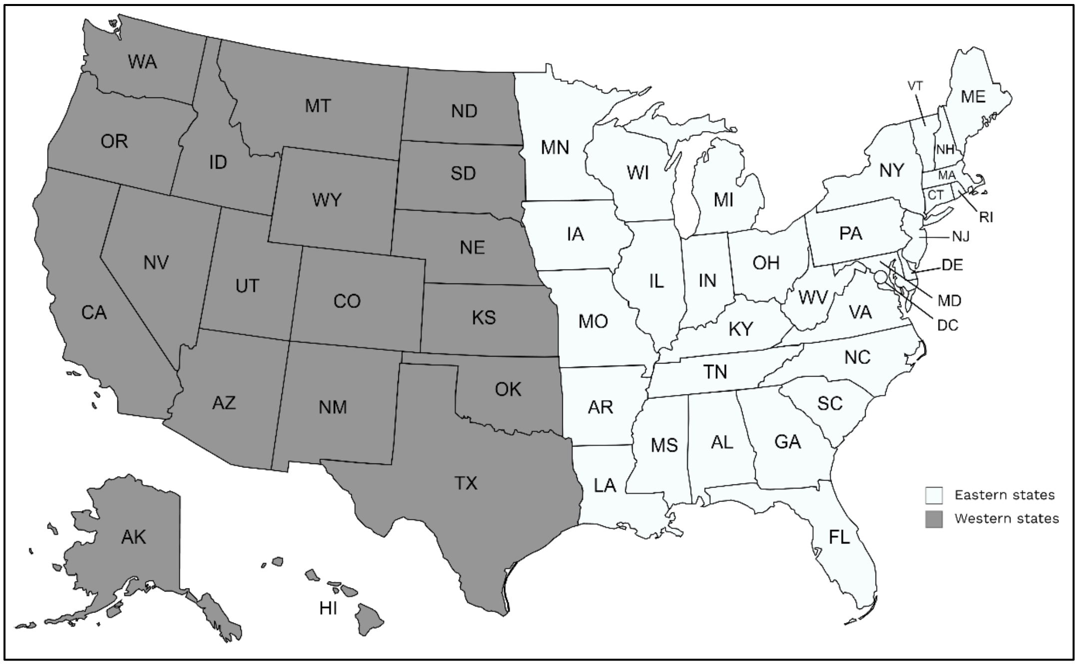

Figure 1. Delineation of eastern and western states referred to in the text. Map created with mapchart.net.

Table 1. List of target bat species to evaluate for use of transportation structures.

Common name	Latin name	Federal status
Indiana bat	*Myotis sodalis*	Endangered
Gray bat	*Myotis grisescens*	Endangered
Northern long-eared bat	*Myotis septentrionalis*	Threatened*
Tricolored bat	*Perimyotis subflavus*	Proposed Endangered**
Little brown bat	*Myotis lucifugus*	Under Review

*final rule on uplisting to endangered expected to take effect March 31, 2023
**decision expected September 9, 2023

2 LITERATURE REVIEW

Information gathered though extensive literature review and communication with federal and state agencies in the U.S. fell into the following categories: structure survey methods, types of structures used and avoided, percentage of structure use by bats, how bats use structures (e.g., maternity colonies, bachelor colonies, night roosts, migration stops), and species use. A total of 191 documents were reviewed for this report.

2.1 Structure Survey Methods

Visual inspection was the primary method reported in reviewed literature. Other detection methods documented sign such as guano deposits or staining from urine and audible sound or acoustic survey using an ultrasonic bat detector. Survey techniques are described in more detail in Section 3.2.

2.2 Types of Structures Used and Avoided

It was estimated that only 1% of America's bridges are suitable for use as bat roosts (Keeley and Tuttle 1999). Bat use of transportation structures is based on several factors including the amount of suitable natural roosts in the surrounding habitat, the materials and design of the structure, and the location of the structure relative to solar exposure and protection from adverse weather or human threats. Roost temperature is crucial to bats, so structures with solar exposure that hold heat are important. Bridges constructed from concrete over water and near forest provided the necessary thermal requirements and were the most common bridge structure used across all studies found. In particular, bats prefer parallel box beam and prestressed girder type bridges.

Figure 2. Prestressed concrete box beam bridge with expansion joints suitable for bat use (Photo by Copperhead Consulting).

An exception to this is the use of timber-constructed bridges as roosts by eight bat species in New Mexico (Geluso and Mink 2009). Suggestions for this discrepancy were the larger roosting spaces compared to I-beam bridges and that these wooden bridges were old, so the creosote was not fresh (Geluso and Mink 2009). Bats are less likely to be found in metal structures or wooden bridges that contain creosote such as railway bridges. Sizes of structures vary greatly, but the presence of roosting locations such as cracks, expansion joints, and weep holes are important. In general, longer bridges require more expansion joints and hinges providing more areas for bat roosting, but preference for bridges 100-200 ft long has been documented (Erickson et al. 2002). Additionally, bats used structures that were built between 1910 and 1945 more than newer bridges, likely due to deterioration of the bridge providing more suitable roosting areas. In more recent years, transportation departments have started building more slab-type bridges which lack many hinges or expansion joints and do not provide many roosting options for bats (Erickson et al. 2002).

Culvert use has been studied less than bridges, but it was generally thought that bats preferred culvert sizes 5 – 10 ft in height and greater than 328 ft in length (Keeley and Tuttle 1999). In New Mexico, researchers documented minimum culvert heights of 2 ft for bats of the *Myotis* genus of unreported species (WNSCRWG 2018), however none of the target species for this report are found in New Mexico. The USFWS Asheville, NC Field Office summarized minimum culvert dimensions from a review of published and unpublished surveys and found that the smallest height of culvert used by bats was 2 ft in Mississippi and the shortest length was 23.3 ft in Louisiana. In Missouri, the smallest culvert sizes used by bats was 9 ft tall and 250 ft long and it was a metal culvert used by two northern long-eared bats (USFWS 2022d). Cast-in-place concrete box culverts were the favored type of culvert used by bats in many studies, though metal and concrete pipe culverts also got used (Bender et al. 2010, USFWS 2022b). It is likely that culvert size has less influence on bat use compared to other factors such as surrounding habitat or lack of other roosting options.

In Texas, Keeley and Tuttle (1999) found cave myotis (*Myotis velifer*) roosting regularly in abandoned swallow nests (birds in the Hirundinidae family) in concrete box culverts. More recently, the California Bat Working Group (CBWG) identified bats roosting in swallow nests on bridges and culverts throughout the year. In Missouri, *Myotis* species of bats have been documented in bird nests under a bridge (B. McMurray, MoDOT, pers. comm). Five species of bats have been documented roosting inside nests, in the interstitial crevices between nests, between the nest and the structure, and sometimes even with swallow nestlings. At one location, over 80% of abandoned swallow nests contained bat guano (CBWG 2022). In the eastern U.S., Georgia has had some occurrence records of big brown bats (*Eptesicus fuscus*) and a potential *Myotis* sp. using cliff swallow nests (*Petrochelidon pyrrhonota*) on bridges, but it seems to be rare and coinciding with cold weather snaps in the late spring (K. Morris, GADNR, pers. comm.). There was very little published information on bats using bird nests in the eastern U.S., but documenting evidence of bats roosting bird nests on structures is included on bats in bridges survey datasheets in Georgia and Kentucky.

2.3 Percentage of Structures Used by Bats

Of all the literature found, there were 21 transportation structure survey studies where the main goal was to identify how many structures were being used by bats. Combined, these found bats using 13.8% of the surveyed structures (1,198 structures with bat use/8,648 structures checked). However, percentage of structures with bat use ranged from 3.4% – 88.0% (Table 2). This large range in detection is likely due to the survey techniques and methodologies. In some studies, all bridges available in the study area were examined, but in others, only select bridges with preferred habitat were inspected. Nineteen studies were conducted in individual states, one in New England (Civjan et al. 2017a,b), and one was a compilation of data from 25 states (Keeley and Tuttle 1999).

Table 2. Summary of bat use of transportation structures in reviewed sources.

State of study	# bats / # structures searched	% of structures with bats	Citation	Notes
Alabama	3/4	75%	Bender et al. 2010	Cast-in-place box culverts
Arkansas	21/164	12.8%	Sasse 2019	Gray bat migration
Arkansas	11/193	5.7%	Lamb et al. 2022	Tricolored bats in culverts
Florida	151/479	31.5%	Gore and Studenroth 2005	Random & intentional

State of study	# bats / # structures searched	% of structures with bats	Citation	Notes
Georgia	55/540	10.2	Cleveland and Jackson 2013	
Iowa	124/517	24%	Bektas et al. 2018a	
Illinois	15/232	6.5%	Feldhamer et al. 2003	7.4% of usable bridges (15/202)
Louisiana	32/81	39.5%	Lance et al. 2001	59.6% of concrete girder bridges (31/52). Guano under 51 bridges (63%)
Mississippi	7/99	7.1%	Trousdale and Beckett 2002	Southern part of state
Mississippi	36/90	40%	Trousdale and Beckett 2004	
Mississippi	191/391	48.8%	Rosamond et al. 2018	Culverts in January in 2 yrs
Montana	12/130	9.2%	Hendricks et al. 2005b	4 bridges used by maternity colonies
North Carolina	135/990	13.6%	McDonnell 2001	Coastal plain
North Carolina	15/423	3.5%	Felts and Webster 2003	Southeastern NC
Nebraska	57/280	20.4%	NDOR 2016	
New England	13/191	6.8%	Civjan et al. 2017a,b	Northern
New Mexico	15/17	88.2%	Geluso and Mink 2009	
South Carolina	38/1,129	3.4%	Bennett et al. 2008	All Rafinesque's big-eared bats
Texas	14/70	20%	Meierhofer et al. 2018	Mexican free-tailed bats in box-beam bridges. Additional 17 bridges (24%) had bat sign.
Texas	42/207	20.2	Meierhofer et al. 2019	All tricolored bats in culverts, during hibernation.
25 states	211/2,421	8.7%	Keeley and Tuttle 1999	bridges and culverts; 714/2421 used as night roosts
Total	**1,198/8,648**	**13.8**		

2.4 How Bats Use Structures

According to the sources we consulted, bats use transportation structures throughout the year across the U.S. as maternity, bachelor, hibernacula, and migration roosts both as day and night roosts (Table 3).

2.4.1 Night Roosts

Bats of all ages and reproductive conditions use bridges and culverts as night roosts and day roosts. The most common species found night roosting were of the *Myotis* genus, big brown bats, and big-eared bats (*Corynorhinus* spp.; Keeley and Tuttle 1999). These structures remain warm at night and provide protection from predators. These are important factors for bats digesting meals or attending to pups that are traveling with mothers. Night roosting usually occurs between 10pm and midnight, but bats can remain most of the night.

2.4.2 Day roosts

Day roosts are those roosts used by bats from sunrise to sunset. Keeley and Tuttle (1999) found that bridges and culverts are used during the day by both bachelor and nursery colonies, as temporary roosts during migration and mating, and sometimes as hibernacula in the southern states. The number of bats using a day roost fluctuates throughout the year at most structures. In most states where studies were conducted (Table 2), structures are used from April – October, but in some southern states, structures get year-round use. Bridge and culvert use is not as common above the middle of the country (Missouri is south of this line), but roosts have been documented in Vermont, Maine, Montana, and Massachusetts (Civjan et al. 2017a,b; WNSCRWG 2018).

Table 3. Citations for how bats use transportation structures.

Citation	Location	Night roosts	Day use	Mater-nity	Hiber-nacula	Swarming/ mating	Migratory stopover	Bachelor
Adam & Hayes 2000	Oregon	X						
Arnett & Hayes 2000	Oregon		X					
Bennett et al. 2008	South Carolina			X				
Ceľuch & Ševčík 2008	Slovakia				X	X		
Cervone et al. 2016	Indiana	X	X		X	X	X	
Civjan et al. 2017a,b	New England	X		X				
Davis & Cockrum 1963	Arizona	X	X	X			X	X
Feldhamer et al. 2003	Illinois		X					
Ferrara & Leberg 2005a	Louisiana	X	X	X	X			
Fraze & Wilkins 1990	Texas						X	
Geluso & Mink 2009	New Mexico							
Gloza et al. 2001	Germany				X			
Harrje 1994	Germany				X			
Hendricks et al. 2005a,b	Montana			X				
Hirshfeld et al. 1977	Arizona, Nevada	X						
Johnson et al. 2002	Georgia	X						

Citation	Location	Night roosts	Day use	Mater-nity	Hiber-nacula	Swarming/ mating	Migratory stopover	Bachelor
Katzenmeyer 2016	Mississippi				X			
Keeley & Keeley 2004	Texas		X		X			
Keeley & Tuttle 1999	25 States	X	X	X		X	X	X
Kiser et al. 2002	Indiana	X						
Lamb et al. 2022	Arkansas		X		X			
Lance et al. 2001	Louisiana		X					
Lewis 1994	Oregon	X						
Meierhofer et al. 2018 and 2019	Texas	X	X		X			
Perlmeter 1996	Oregon	X		X				
Pierson et al. 1996	California	X						
Sandel et al. 2001	Texas				X			
Sasse 2019	Arkansas						X	
Stager 1943	California		X					
Trousdale & Beckett 2002	Mississippi		X	X				

2.5 Species Use

All target species for this review have been documented roosting in transportation structures (Table 4). Additionally, at least 20 other bat species have been documented roosting in structures throughout the country (Appendix A).

Table 4. State occurrence of target species using transportation structures and corresponding source.

Species by State	Source	Structure Type	Roost Type/Notes
Myotis sodalis			
IN	Cervone et al. 2016	Bridge	Swarming, migratory stopover
IN	Kiser et al. 2002	Bridge	Day and night roost
IN	Mumford and Cope 1958		
KY	Copperhead data		
NC	Knepp and Miller 2022		
Unknown	Barbour and Davis 1969		

Species by State	Source	Structure Type	Roost Type/Notes
WV	Alex Silvis – WVDNR		
WV	Owen et al. 2001		
WV	Sydney Burke – WVDOH		
Myotis septentrionalis			
AR	Blake Sasse – AGFC		
IL	Feldhamer et al. 2003	Bridge	Day and night roost
IN	Kiser et al. 2002	Bridge	Day and night roost
LA	Ferrara and Leberg 2005b	Bridge	Day roost
MO	B. McMurray (pers. comm.)		
MO	USFWS 2022d	Culvert	
NC	Knepp and Miller 2022		
NC	NCDOT 2021		
VT	Civjan et al. 2017a,b	Bridge	Day roost
Myotis grisescens			
AR	Sasse 2019 (during migration)	Bridge	Day roost
GA	Johnson et al. 2002	Bridge	Night roost
IN	Cervone et al. 2016	Bridge	Single bat
KY	Copperhead data	Bridge	Maternity roost
KY	USFWS 2020	Bridge	Day and night roost
MO	B. McMurray (pers. comm.)		
NC	Etchison and Weber 2020	Bridge	Day roost
NC	Knepp and Miller 2022		
NC	NCDOT 2021		
NC	USFWS 2022d	Culvert	
TN	Copperhead data		
Unknown	Barbour and Davis 1969		
Myotis lucifugus			
ID	Keeley and Tuttle 1999	Bridge	
IL	Feldhamer et al. 2003	Bridge	Day roost
IN	Cervone et al. 2016	Bridge	Maternity roost, swarming, migratory stopover
IN	Kiser et al. 2002	Bridge	Night roost
MT	Hendricks et al. 2005b	Bridge	Day and night roost
NC	Knepp and Miller 2022		
NC	NCDOT 2021		
OR	Adam and Hayes 2000	Bridge	Night roost
OR	Perlmeter 1995	Bridge	Night roost
TN	Copperhead data		
VT	Civjan et al. 2017a,b	Bridge	Day roost
Perimyotis subflavus			
AR	Lamb et al. 2022		

Species by State	Source	Structure Type	Roost Type/Notes
GA	Lutsch et al. 2022	Culvert	Hibernacula
IL	Feldhamer et al. 2003	Bridge	Day roost
IN	Cervone et al. 2016	Bridge	Hibernacula
IN	Kiser et al. 2002	Bridge	Night roost
KY	Gumbert 1999	Bridge	Maternity
LA	Ferrara and Leberg 2005b	Bridge	Hibernacula
LA	Lance et al. 2001	Bridge	Day roost
MN	Geluso et al. 2005	Culvert	
MO	B. McMurray (pers. comm.)		
MO	Lutsch 2019	Culvert	Hibernacula
MS	Katzenmeyer 2016	Culvert	Hibernacula
MS	Martin et al. 2006	Culvert	
NC	Felts and Webster 2003	Bridge	Day roost
NC	Knepp and Miller 2022		
NC	McDonnell 2001	Bridge	Day roost
NC	USFWS 2022d	Culvert	
SC	Bennett et al. 2008	Bridge	
TX	Sandel et al. 2001	Culvert	Hibernacula

2.6 Target Species

2.7 Indiana Bat (*Myotis sodalis*)

The Indiana bat was listed as an endangered species on March 11, 1967 under the Endangered Species Preservation Act of 1966. The species ranges from Michigan and parts of New York in the north, west of the Appalachian Mountains south to the northern half of Alabama and west to Arkansas, Missouri, and southern Iowa. Critical Habitat was designated for the species on September 24, 1976 and includes 11 caves and three mines in six states in the eastern U.S.

During the winter months, Indiana bats are restricted to suitable underground hibernacula typically consisting of caves located in karst areas of the east-central United States. However, this species also hibernates in cave-like locations, including abandoned mines.

During the spring, summer, and fall, the Indiana bat uses a variety of forested habitats for roosting, foraging, and commuting. These habitats include forest blocks and woodlots, as well as linear features such as fencerows, riparian forests, and other wooded corridors. These wooded areas may be dense or loose aggregates of trees with variable amounts of canopy closure. Isolated trees may be used as roosts if they exhibit the characteristics of a suitable roost tree and are located within 1,000 feet of other suitable habitat. Suitable roosting habitat consists of live or dead trees and snags with a diameter at breast height (DBH) of five inches or greater that possess any or all of the following characteristics: exfoliating bark; cavities, crevices, or cracks; or dead or dying trunk/branches. Roost trees are typically located within canopy gaps, along a fencerow, or along a wooded edge.

Maternity colonies are typically found in dead or dying trees with larger DBH (at least nine inches) that receive direct sunlight for more than half the day. Maternity roosts have been documented in riparian zones, bottomland and floodplain habitats, wooded wetlands, and upland communities. Foraging habitat for the Indiana bat includes closed to semi-open forested habitats, where bats forage along forest edges and above the tree canopy. Commuting habitat includes forested blocks and corridors that connect roosting and foraging areas.

In addition to natural roosts, Indiana bats will roost in bridges. Between October 2006 and April 2011, there were 878 observations of Indiana bats roosting in a bridge in Indiana (Cervone et al. 2016). This was the only bridge documented to have bat use out of the "over 200" surveyed. It was a metal bridge with 10 concrete girder spans with cracks and crevices located on a two-lane road over a large undisclosed river. The location of the deep concrete sidewalls placed into a hillside "creates the appearance of a cave." Bats roosted in seams with an average width of 2.9 mm or in gaps created by loose concrete. This bridge is within 25 miles of a dozen Indiana bat hibernacula, including one of the largest in the species range, and within 2 miles of a maternity colony. Bats used the bridge as a day and night roost during the spring, summer, and fall and is believed to be used as a migratory stopover. During the summer of 1998, Kiser et al. (2002) found Indiana bats night roosting in three bridges with concrete girders over creeks at Camp Atterbury in central Indiana. In addition to the 80 Indiana bats observed night-roosting, two Indiana bats day-roosted singly on two different days. An Indiana bat maternity colony was documented day roosting under a concrete bridge (Figure 3) over a creek in Kentucky (Roby 2018). Indiana bats have been tracked to bridges in Illinois (Copperhead data), juvenile females were collected from roosting under an unknown bridge type in Mississippi (A. McCartney, USFWS, pers. comm.), an adult female was tracked to a concrete bridge roost during spring migration in Tennessee (Roby and Gumbert 2014), and three Indiana bats were found on a bridge during fall migration in Missouri (C. Shulse, MoDOT, pers. comm.).

Indiana bats have been documented in 52% of Missouri counties with a total of 389 location records (Roby 2022). There are six caves in five Missouri counties (Crawford, Franklin, Iron, Shannon, and Washington) that are designated critical habitat for Indiana bats (USFWS 1976). As of the 5-year review for Indiana bats (USFWS 2019), the largest known hibernaculum for the species was Sodalis Nature Preserve in Hannibal, MO accounting for 36.3% of the population.

Figure 3. Indiana bats roosting under a concrete bridge in north central Kentucky, 6 September 2018. (Photo by Copperhead Consulting)

2.8 Gray Bat (*Myotis grisescens*)

The gray bat was listed as endangered under the Endangered Species Act (ESA) on April 28, 1976, but no critical habitat has been identified. The range of the species includes the southern half of Illinois, Indiana, and Ohio; the western portions of West Virginia, Virginia, North Carolina, and Georgia; all of Kentucky, Tennessee, and Alabama; northern Mississippi; the northeast quarter of Arkansas; and the eastern half of Missouri.

The gray bat typically roosts in caves year-round and is often found in large numbers, with colonies in excess of one million individuals reported (Brady et al. 1982). Habitat requirements for roosts are highly specific, with fewer than 5 percent of caves representing suitable habitat (Tuttle 1979). The gray bat utilizes varying types of caves during different times of the year, including caves with deep vertical shafts that provide a cold air trap during winter (hibernacula) and caves with domed ceilings that trap warm air during summer for maternity colonies. Other caves, known as dispersal caves, are used as roosting sites during migration between maternity caves and hibernacula. However, gray bats have been documented to use trees as roosts during migration (Samoray et al. 2020). Gray bats are also known to use bridges as roosting habitat during the spring, summer, and fall (Sasse 2019). Gray bats have been found roosting in bridges as day and night roosts in many states (Barbour and Davis 1969, Martin 2007, USFWS 2020). They have been found in Kentucky and North Carolina using expansion joints of concrete bridges as maternity roosts (Copperhead data, Etchison and Weber 2002), in southwest Virginia and western North Carolina using concrete box culverts as maternity roosts (Powers et al. 2016, Weber et al. 2020), in Georgia roosting on the concrete ceiling under the middle of the east end of a bridge (Johnson et al. 2002), and in Missouri roosting between the concrete decks and tops of plywood forms used for concrete patching operations (C. Shulse, MoDOT, pers. comm.) and other bridges in the southern part of the state (B. McMurray, MoDOT, pers. comm.). Dead gray bats have also been found frozen on a bridge in late fall, presumably during migration (C. Shulse, MoDOT, pers. comm.). Gray bats usually forage for insects in riparian areas or over open water bodies such as rivers, streams, lakes, or reservoirs which could regularly bring them into contact with bridges and culverts. Commuting habitat for the gray bat primarily consists of wooded corridors used to travel between roosting and foraging habitat.

In Missouri, gray bats have been documented in 66 counties (active season use in 16 counties, inactive season use in 11 counties, and 39 counties with documented active and inactive use) with most of the population residing south of the Missouri River (ICF 2022). Gray bats have been documented in at least 219 Missouri caves represented by 49 maternity caves, 13 hibernacula, 125 transient and/or bachelor sites, and 32 that are no longer used by this species (Elliott 2008). The most recent state population estimate is 772,817 from the four major gray bat hibernacula in Missouri (Colatskie 2017), accounting for approximately 20% of the total population of the species (MDC 2023).

2.9 Northern Long-eared Bat (*Myotis septentrionalis*)

In 2016, USFWS published rules under Section 4(d) (81 FR 1900, January 16, 2016) of the ESA meant to protect the northern long-eared bat while minimizing regulatory requirements for landowners, land managers, government agencies, and others within the species' range. On March 22, 2022, the USFWS announced a proposal to reclassify the northern long-eared bat as endangered under the ESA. This reclassification was finalized in November 2022 and is expected to become effective March 31, 2023, thus nullifying the 4(d) Rule. The USFWS has not designated or proposed any critical habitat for this species.

The northern long-eared bat range includes parts of three provinces in southeastern Canada, east to the coast and south into the U.S. through most of North Carolina, northwestern South Carolina, northern portion of Georgia, northern half of Alabama, northern 75% of Mississippi, northern half of Louisiana, and west to eastern Oklahoma, eastern half of Kansas, most of Nebraska, and the eastern edges of Wyoming and Montana. This species uses different habitats during the summer and winter months. Hibernacula that are used in winter vary from large caves and abandoned mines with large entrances and passages to smaller features. Preferred features have relatively constant, cool temperatures (32 to 48°F), high humidity, and minimal air currents. This species typically roosts in small crevices and cracks in walls and ceilings; however, individuals have also been observed roosting in the open, although less frequently. In addition to mines, northern long-eared bats have been found hibernating in man-made structures such as buildings, barns, utility poles, bat houses, and bridges.

During the spring, summer, and fall, the northern long-eared bat uses a variety of forested habitats for roosting, foraging, and commuting, including forest blocks and woodlots, as well as linear features such as fencerows, riparian forests, and other wooded corridors. These forested areas may be dense or loose aggregates of trees with variable amounts of canopy closure. Suitable roosting habitat consists of live or dead trees and snags with a DBH of three inches or greater that have exfoliating bark, crevices, cavities, or cracks. This species is more likely to roost in crevices, cracks, and cavities than other *Myotis* species and is more opportunistic when selecting a roost tree, often utilizing shorter trees with smaller DBH and tree stumps.

Foraging habitat includes mature upland forests along hillsides and ridges. This species may also forage in more open areas such as forest clearings, over open water, and along roads; however, it is less likely to forage in riparian areas.

Northern long-eared bats have been documented on occasion day roosting in bridges. In Illinois, northern long-eared bats made up < 3% of the bats found day rooting in bridges (Feldhamer et al. 2003). Of the 15 northern long-eared bats documented in that Illinois study, over half were in parallel box beam bridges (n = 7 bats), four bats were found in I-beam bridges built with a combination of steel and concrete, two bats were in prestressed concrete girder bridges, and two were found in cast-in-place bridges. Kiser et al. (2002) found northern long-eared bats using six concrete girder bridges in Indiana as day and night roosts, which was approximately 7% of the bats they found using bridges. Of the 1,992 bats found in 99 bridges visited in Louisiana, all were located in "double-T" concrete bridges, including seven northern long-eared bats (Ferrara and Leberg 2005a). The first maternity colony of northern long-eared bats for Louisiana was discovered in summer 2022 roosting under an unknown bridge type, as well as northern long-eared bats of unknown sex and age under two additional bridges (A. McCartney, USFWS, pers. comm.). Finally, a single northern-long eared bat was documented roosting with a maternity colony of little brown bats in the ceiling of a covered wooden timber bridge in Vermont (Civjan et al. 2017b). Culvert use by this species is less well documented, but in Missouri, a metal culvert was used by two northern long-eared bats (USFWS 2022d).

Northern long-eared bats can be found throughout Missouri. There have only been 25 maternity colonies documented in the state, but there are another 207 probable maternity colonies based on "summer capture records" that incorporates all sex and age combinations (Missouri Department of Conservation data). More than 269 hibernacula have been found in Missouri, accounting for 23% of all known hibernacula in the U. S., although most counts only include a few individuals (USFWS 2018a). This species has been severely impacted by the arrival of WNS as evidenced by a maximum number of 38,131 individuals historically recorded in 29 states to the 19,356 recorded individuals in 18 states in 2020 (USFWS 2022). Therefore, any roost documented, especially anthropogenic such as a bridge that is likely more stable (as opposed to the impermanence of senescent trees), would inform on roosting requirements for this species and help develop protection measures when northern long-eared bats are present.

2.10 Tricolored Bat (*Perimyotis subflavus*)

The tricolored bat was proposed for listing as Endangered under the ESA on September 13, 2022, and is anticipated to receive protection by September 2023. However, the specific protections for this species have yet to be determined.

The tricolored bat was previously classified as the eastern pipistrelle, *Pipistrellus subflavus* (Hoofer 2006) and inhabits parts of six countries including the eastern half of the United States, Mexico, Guatemala, Honduras, Belize, and Nicaragua. However, there are records of westward expansion into New Mexico, South Dakota, Texas (Geluso et al. 2005), and more recently, Colorado (Adams et al. 2018). The populations were secure until the introduction of WNS, after which a 93% decline has been documented across 59% of the species range (Cheng et al. 2021).

The tricolored bat is less selective than other cave-roosting species and overwinters in a variety of habitats throughout the range including caves, mines, road culverts, bridges, and tunnels.

Though hundreds of individuals may be found in the same roost, tricolored bats generally roost singly, use deep torpor (decreased physiological activity), and are often found covered in condensation. Early studies found this species entered hibernation earlier and stayed later than other bats, but more recent observations show tricolored bats may be spending less time in hibernation, possibly due to behavioral changes associated with the introduction of WNS.

Tricolored bats spend summers roosting independently or in small groups in dead leaf bundles hanging in live or dead trees, buildings, basal cavities of swamp trees (e.g., tupelo, sweetgum), caves, rock crevices, road culverts, and bridges. The species primarily forages in the open over water, but wing morphology does allow for slow flight adapted for the more cluttered environments where they are often found roosting outside of the hibernation season.

Tricolored bats often use bridges and culverts for roosting. Cervone et al. (2016) made 29 observations of tricolored bats (then called eastern pipistrelle bats) roosting under a bridge in Indiana. This is the same bridge under which Indiana bats were found and described in Section 2.7 above. These bats were only found under the bridge in the winter and spring suggesting they use the bridge as a hibernaculum (Cervone et al. 2016). Also in Indiana, Kiser et al. (2002) found tricolored bats roosting under concrete-girder bridges during the summer. Tricolored bats have been found roosting in crevices of parallel box beam bridges in Illinois (Feldhamer et al. 2003), by a maternity colony in concrete girder bridge in Kentucky (Gumbert 1999), and multiple maternity colonies under timber multi-beam bridges in North Carolina (McDonnell 2001). Winter records include under concrete “double-T” bridges in Louisiana (Ferrara and Leberg 2005b), concrete box-type culverts in Texas (Sandel et al. 2001, Meierhofer et al. 2019) and Mississippi (Katzenmeyer 2016), and primarily in weep holes in Georgia culverts (Lutsch et al. 2022). Also in Georgia, more tricolored bats were found farther south in the state, an area farther from traditional cave hibernacula, than the northern part of the state (Ferrall 2022). It is likely that other southern states house this species in bridges and culverts in the winter, but public data are sparse.

Tricolored bats have been documented in 88 of Missouri’s 114 counties (ICF 2022), but before WNS, tricolored bats were likely found throughout the state (Boyles et al. 2009). Data suggest that the tricolored bat population has declined by more than 50% in Missouri since 2012. Although roosts are not limiting for this species like they are for Indiana bats, the maintenance of non-ephemeral roosts could support the bats that survive WNS. Hammesfahr et al. (2020) surveyed 28 mist-net nights in 2018 and 33 mist-net nights in 2019 within Missouri Department of Conservation (MDC) conservation areas in Shannon, Carter, and Reynolds counties in southeast Missouri and only captured two tricolored bats.

2.11 Little Brown Bat (*Myotis lucifugus*)

The little brown bat is currently under review for listing under the ESA. Little brown bats can be found throughout most of the United States and Canada although it is generally absent from the southern Great Plains region.

Little brown bats have been documented using human dwellings such as barns, sheds, attics, and buildings for roosting in the summers, as well as artificial roost structures such as artificial bark (i.e., BrandenBark®) and bat boxes. However, they are also known to use trees, natural crevices, and rock crevices.

During the summer months, female little brown bats have been documented primarily using hot, dark, and poorly ventilated buildings for maternity day roosts while adult male bats roost either individually or in small groups in rock crevices, tree hollows, loose tree bark, or small openings in buildings separate from the maternity roost (Humphrey and Cope 1976). It is assumed that prior to construction of man-made structures, little brown bats used hollow trees and rock crevices as maternity roosts, however other published documentation of natural roosts used by little brown bats is uncommon (Barclay and Cash 1985). Foraging habitat includes margins and edges of waterbodies and overtop of waterbodies (Fenton and Barclay 1980).

Winter hibernacula for little brown bats includes caves and abandoned mines with high humidity levels and temperatures above freezing (Fenton and Barclay 1980). Little brown bats will often form clusters of both sexes during hibernation.

Small numbers of little brown bats have been documented roosting in concrete-girder bridges during the summer in Indiana (Kiser et al. 2002) and in crevices of parallel box beam bridges Illinois (Feldhamer et al. 2003). Maternity colonies of little brown bats in bridges have been found in the ceiling of a covered bridge in Vermont (Civjan et al. 2017b) and on a wood girder in Montana (Hendricks et al. 2005b). A large maternity colony of 300 individuals found on an unknown bridge type in Idaho was the northernmost day roost found in bridges for this species (Keeley and Tuttle 1999).

Prior to the arrival of WNS, little brown bats were thought to be found throughout the state of Missouri (Boyles et al. 2009). Historical data shows little brown bats have been found hibernating in caves and mines in 61 Missouri counties (ICF 2022). There are no known little brown bat summer colonies in natural trees in Missouri. Little brown bats heavily rely on anthropogenic roosts including bridges.

3 CURRENT AND EMERGING TECHNIQUES

3.1 DOT and Agency Practices

State, federal, and DOT agencies (Table 5) responding to the questionnaire indicated that transportation structures are primarily surveyed by visual inspection using a light source, binoculars, borescope cameras, and thermal cameras to document bats (Table 6). Sometimes emergence surveys are performed if bats are suspected but not seen during initial investigations, which can be useful in estimating colony size/extent of use. Deterring bats from structures is not a common practice among DOTs but has been successful in Georgia. Excluding bats when necessary is most often done by sealing joints and weep holes when the structure is not occupied. Another practice is using backer rod or pool noodles to temporarily keep bats out of roosting areas. Several DOTs and other agencies have created bat survey forms for transportation structures, some of which are included in Appendix B. There are also several training courses and handbooks available that are helpful for determining bat use of transportation structures (Appendix C).

When a transportation structure slated for maintenance, rehabilitation, or replacement is being used by federally listed bat species for roosting, ESA Section 7 consultation with the USFWS is required. Beyond using the Programmatic Biological Opinion for Transportation Projects in the Range of the Indiana Bat and Northern Long-Eared Bat (Range-wide BO; USFWS 2018a), some

DOTs in coordination with the Federal Highway Administration (FHWA) in the eastern U.S. have gone into formal consultation with their USFWS field offices to develop programmatic biological opinions (PBO) to address potential impacts to federally listed bats (including gray bats). These PBOs help DOTs batch projects with similar determinations, streamline consultations, reduce administrative costs, and improve project schedules (USFWS 2018b, USFWS 2020).

Table 5. List of agencies responding to questionnaire regarding bats in transportation structures.

Agency	Respondent title
Arizona Game and Fish Department	Statewide Bat Specialist
Arkansas Game and Fish Commission	Nongame Mammal/Furbearer Program Leader
Georgia Department of Natural Resources	Wildlife Biologist, Environmental Review Coordinator
Pennsylvania Game Commission	Threatened and Non-Game Mammal Section Supervisor
West Virginia Department of Natural Resources	Endangered Species Biologist
Missouri Department of Transportation	Threatened and Endangered Species Biologist
Tennessee Department of Transportation	Ecology Section Manager
West Virginia Department of Highways	Endangered Species Specialist
Tennessee Valley Authority	Terrestrial Zoologist/Biological Permitting and Compliance

Table 6. Responses to questionnaire from agencies.

	TVA	AZGFD	AGFC	VDOT	GADNR	PAGC	WVDNR	MoDOT	TDOT	WVDOH
How does your organization survey for bats in structures?										
Require Training	X									
Desktop Assessment										X
Survey/Data Collection Form				X	X					
Visual Inspection	X	X	X				X	X		
Binoculars		X		X	X		X	X		
Spotlight/Flashlight		X	X	X	X			X		

	TVA	AZGFD	AGFC	VDOT	GADNR	PAGC	WVDNR	MoDOT	TDOT	WVDOH
Mirror				X						
Ladder				X						X
Yardstick			X							
Borescope/Camera	X	X			X			X		X
Thermal Cameras	X				X	X		X		X
Emergence Count	X									
Collect Guano Samples				X						
Acoustic Detector								X		
Has your organization had any success deterring bats from structures?										
Yes					X					
Haven't Tried	X			X			X			X
No Response			X						X	
What techniques have been used to exclude bats from structures?										
Backer Rod/Pool Noodles				X	X			X		
Exclusion Boxes										X
Seal Joints/Drains		X			X	X		X		
Hand Remove as Last Resort					X					

3.2 Detecting Bats at Structures

An option to increase success of locating bats in transportation structures occurs prior to visiting bridges and culverts in the field. Some states are relying on building models from desktop data to help target areas with higher probabilities of encountering roosting bats. In Iowa, bridge characteristics (material, structure type, height, and length) are combined with land cover and bat distribution data to target bridges for monitoring (Bektas et al. 2018b). In North Carolina as part of their ATLAS[2] program, NCDOT is using machine-learning models to refine species maps for federally listed species based on bridge and surrounding habitat parameters. Modeling and targeting appears to be a useful tool to focus efforts on areas or specific transportation structures that are most likely to house bats, since structure material and size along with surrounding land use are important factors.

[2] ATLAS = Advancing Transportation through Linkages, Automation, and Screening

Once onsite, detecting bats at structures can be difficult since bats can switch roosts daily and seasonally. Current transportation structure survey techniques involve basic tools; most surveys only include the use of a light source to locate individuals or note evidence of roosting by signs of guano or urine staining. Tools used include binoculars, head lamp or spotlight, camera with a zoom lens, and occasionally borescope or a mirror on a telescoping pole. Although possibly cost prohibitive, using thermal cameras (typically FLIR brand) work well when bats are easily accessible (C. Shulse, MoDOT, pers. comm.). A limitation of using thermal cameras to detect bats in a roost can be that because bats are heterothermic (i.e., body temperature is often similar to the roost) when at rest, it is difficult for the thermal camera to differentiate the heat signature of a bat verses the structure. Researchers have also used acoustic detectors to listen for bat calls in roosts. When roosts are too high or dangerous to access, acoustic detectors have been placed on drones to record bat vocalizations (Fu et al. 2018). VDOT has developed a bat guano and acoustic sampling protocol to identify species in Virginia transportation structures (Taylor et al. 2022). Of all the indicators of bats, identifying the cause of staining on structures is the most difficult (Civjan et al. 2017). An emerging technology is analysis of urine staining to determine if it belongs to bats or non-bats, e.g., water, rust, etc. (Harris et al. 2020, Li et al. 2021). This technology is still in its infancy and has not been widely applied. With all survey methods, single visits to transportation structures are not sufficient for understanding overall bat use of a given structure. H. T. Harvey and Associates (2021) suggest a minimum of one site visit to determine use and then follow up visits each season to gain more detailed information on how the bats are using the structure.

Once bat use has been determined at a structure it is useful to conduct emergence count surveys. Depending on the size and location of the structure and the location of the bats, emergence counts can sometimes be challenging. However, this problem can be overcome by attaching a thermal camera to a drone (E. Black, Canebrake Environmental Services, pers. comm.) that can survey large bridges or those that cannot be surveyed in their entirety due to safety or logistical concerns.[3] Night vision goggles, have been used during emergence counts and were found to increase the accuracy of the count up to 25% (H.T. Harvey & Associates and HDR 2021).

3.3 Deterring Bats from Structures

The desire to keep bats out of a building, structure, or area is not an uncommon one. Currently, the Transportation Research Board is funding research to develop a handbook for state DOT environmental staff and design/maintenance engineers on how to select and implement methods to temporarily deter and/or exclude bats from transportation structures prior to and during construction and maintenance activities. This is expected to be completed in 2025.

Several methods of deterring bats from areas have been tested and are described below.

3.3.1 Ultrasonic Acoustic

Ultrasonic deterrents emit sounds that are typically outside of human hearing range but within a bat's hearing range. An acoustic bat deterrent emitting white noise over 10kHz – 100kHz developed by Deaton Engineering (DEI) for Bat Conservation International (BCI) has had positive results deterring big brown, eastern red, hoary, little brown, silver-haired, and tri-colored

[3] Example video by Canebrake Environmental Services: https://youtu.be/RXWJe-c9wsc

bats at wind energy facilities in the United States (Arnett et al. 2013) and foraging areas over water. At a church in the United Kingdom, the product was successful at deterring *Pipistrellus pipistrellus* and *P. pygmaeus* bats from specific roosting areas (Gilmour 2019). This product is not currently publicly available, but DEI and BCI are currently working on a new design adding alternate ultrasonic waveforms, increased coverage, and remote control and monitoring.

There are currently two commercially available systems used to deter bats from structures: the BD100 from Binary Acoustic Technology and NRG's Bat Deterrent System. Both are ultrasonic acoustic deterrents that were originally developed for and tested at wind energy facilities. These deterrents work by interfering with a bat's ability to echolocate, making entering a treated space less desirable.

3.3.1.1 Binary Acoustic Technology, BD100 Ultrasonic Bat Deterrent[4]

This deterrent emits two effective beam widths and covers a 12-ft radius. The maximum transmitting power of this unit is 96 decibels (dB) at 50 kilohertz (kHz). For reference, the hearing range of *Myotis* bats is approximately 10 – 115 kHz, and for at least one little brown bat, maximum sensitivity was 110 dB at 40 kHz (Dalland 1965). This low-powered deterrent system was tested at two bat resources: a pond in Arizona and a building roost in Florida inhabited by southeastern bats (*Myotis austroriparius*) and Mexican free-tailed bats (*Tadarida brasiliensis*; EPRI 2019). The best results were observed at the drinking site in Arizona, but both sites showed promising results and the deterrent should be tested further.

Figure 4. BD100 Bat Deterrent (from Binary Acoustic Technology website[5]).

3.3.1.2 NRG Systems, Bat Deterrent System[6]

This deterrent emits 20kHz – 50kHz ultrasound from six individual solid-state speakers that are sealed from the elements. The NRG system was tested at several bridges in Georgia in 2018 (Powell et al. 2018). In one case, the system was used successfully by targeting the bridge in

[4] http://binaryacoustictech.com/batpages_files/bd100.htm
[5] http://binaryacoustictech.com/
[6] https://www.nrgsystems.com/products/bat-deterrent-systems/detail/bat-deterrent-systems/

sections, isolating big brown and Mexican free-tailed bats from areas of active construction. In another case, big brown and Mexican free-tailed bats were excluded from expansion joints with backer rod after the deterrent treatment. Once the exclusion was complete, 98.3% of the colony stopped roosting on the bridge structure. The few bats that were found roosting there prior to construction were physically removed and transferred to an alternate bridge roost. At a different bridge scheduled to be demolished and occupied by a maternity colony of southeastern bats, deterrents were used after pups were volant to successfully deter 100% of the roosting bats during demolition. The deterrents were used for six nights until the remaining bridge was no longer inhabited by bats (Powell et al. 2018).

In Minnesota, Bektas et al. (2021) used the NRG system at bridges (Figure 5) to look at the effectiveness of the deterrent for short-term (ten days) exclusion of little brown bats and long-term (one month) exclusion of big brown bats. After two days of deterrent use, all bats had moved into undeterred abutments. The study noted that the bridges continued to be used as a maternity roost at the sections of bridge that were undeterred, showing that female bats took the pups with them to the undeterred section. Additionally, once the deterrents were turned off, bats returned to the previously deterred abutments the next day at the short-term site and within nine days at the long-term site.

Figure 5. NRG Bat Deterrent System arrangement at bridge. (Photo by Justin Dahlberg used with permission from Bektas et al. 2021)

3.3.2 Light

Another technology that has been investigated includes lighting. Both ultraviolet (UV) and light-emitting diode (LED) methods were shown to be more species dependent than the acoustic deterrents. A study on light’s effect to dissuade bats from wind turbines found that UV lights have no impact on cave-dwelling bats (Cryan et al. 2022). Another study that also found that UV lights have no impact on cave-dwelling bats found that High-Power Sodium (HPS) lights and

LED lights reduced activity by members of the *Myotis* genus but not of the *Eptesicus* genus (Rowse et al. 2016). Additionally, lights, especially those emitting UV, can attract insects and in turn insectivorous bats (Gilmour 2019). Many of the studies that test artificial lighting on bats are not specifically looking at using light to deter bats from structures but to see how urbanization and light pollution affects bats on the landscape. Anecdotal evidence from wildlife control companies suggests that using bright light to deter bats from buildings is seldom effective.

3.3.3 Noise

Bat response to noise in the human hearing range is dependent on individual species sensitivities. Bats in the *Corynorhinus* genus are so sensitive to noise disturbance that they are known to abandon their young, whereas big brown bats tolerated high decibel levels (75-89 dB) of low frequency that were audible to humans[7] from construction equipment (i.e., chain saws, large graders) within 100 feet of their maternity roost. Bats did abandon their roost when high frequency (19-28 kHz) equipment inaudible to human ears was used (H.T. Harvey & Associates and HDR 2021). Additionally, Rowse et al. (2016) found that the noise associated with the generators to power the lights caused less aversion from *Myotis spp*. than to the lights.

3.3.4 Radar

In Europe, one study found that the use of radar on foraging bats reduced activity (Nicholls and Racey 2009), but another found it had no effect (Gilmour 2019). Further testing was done comparing acoustic and radar deterrence, finding that radar methods were ineffective at deterring bats while acoustic methods showed promise (Gilmour et al. 2020).

3.4 Excluding Bats from Structures

Rather than deterring bats from structures while maintenance is conducted, most states choose to exclude bats from structures. The California Department of Transportation (Caltrans) suggests that planning should begin two years prior to the project let date. Exclusion can be temporary or permanent, though permanent loss of roosting habitat should be mitigated for. Common exclusion techniques include the use of one-way doors that allow bats to safely exit but not re-enter (Figure 6) and the use of backer rod or pool noodles to wedge into crevices to guide bats to the one-way door. It is suggested that this method be used for at least a week to ensure all bats are out before sealing joints and hinges. The use of bird netting is not recommended, as it can entangle bats and other wildlife potentially injuring or killing them.

[7] Humans can hear lower frequencies than bats found in the US can. The Caltrans report where this information was found did not provide the frequency of sound created by the chain saws or large graders, but it is assumed to be out of the range of big brown bat hearing. Human range = 0.02 – 20 kHz, general bats range = 10 – 200 kHz.

Figure 6. Photo of one-way door used to exclude bats from expansion joints and hinges (Photo used with permission from H.T. Harvey & Associates and HDR 2021).

3.5 Mitigation

In addition to avoiding and minimizing disturbance to bats using transportation structures, there are some options for mitigating activities that could adversely impact bats. The Range-wide BO for Indiana bats and northern long-eared bats (USFWS 2018a) outlines conservation recommendations for transportation agencies that include protecting known hibernacula, funding research, in-lieu fees, and preserving bat habitat. It is important to remember that mitigation strategies should be species specific and depend on what type of roost is mitigated for (e.g., maternity, bachelor, transitory). Examples of mitigation efforts are described below.

3.5.1 Artificial Roosts

Installation of free-standing artificial roosts is one way to mitigate for the loss of bat roosting habitat. Chambered roosts are typically flat and wide wooden structures that use wooden slats to create small crevices within which bats can roost. These structures are often attached to buildings or can be on a standalone pole and range in size from one chamber that can house a few bats to large structures with multiple chambers that can hold hundreds to thousands of bats. Rocket box style roosts are tall and skinny with a peaked roof and 2 – 3 chambers that are installed on a standalone pole. Artificial bark, such as BrandenBark®, replicates the appearance of natural sloughing bark. Though all these types of artificial roost structures have shown success (Whitaker et al. 2006 [northern long-eared bat, big brown bat, Indiana bat, and little brown bat], Adams et al. 2015 [Indiana bat, little brown bat, and northern long-eared bat], Hoeh et al. 2018 [Indiana bat and little brown bat], Arias et al. 2020 [Indiana bat, little brown bat, and big brown bat, Janos 2022 [evening bat and big brown]), these structures installed as off-site mitigation for bridge replacement projects have shown minimal use (H.T. Harvey & Associates and HDR 2021). During a 4-year bridge replacement project, 40,000 Mexican free-tailed bats were excluded from an old bridge, but only 2,000 bats utilized the seven bat condominiums, designed to hold 7,000 bats each, that were installed as a temporary surrogate roost (H.T. Harvey & Associates and HDR 2021). Multiple additional bridge replacement projects in California also found temporary off-site artificial roost structures to be minimally used by bats excluded from bridges during construction (H.T. Harvey & Associates and HDR 2021). Bat boxes, rocket boxes, and BrandenBark® were used as permanent off-site mitigation for the replacement of two rail bridges in Vermont. No bats were observed roosting in either bridge before bridge removal, but bats were recorded acoustically (Indiana bat, little brown bat, northern long-eared bat, eastern small-footed bat) and captured at the bridges (northern long-eared bat and big brown bat). Preliminary data indicate that bats have used at least one of the structures (Lout 2022).

3.5.2 Bat Friendly Bridges

New bridges and culverts can be designed with characteristics suitable for bats. The Texas Department of Transportation constructed a bat-friendly domed culvert (Keeley and Tuttle 1999). The Arizona Department of Transportation designed a new bridge with cut-outs (Spencer-Glasson 2018) and another bridge with mounting brackets so that bat boxes could be installed (Keeley and Tuttle 1999). Multiple bridges in California have been designed with cast-in-place bat boxes (Figure 7) and concrete panels. Both cast-in-place roost designs have been successful in mitigating for the habitat lost from the old bridge; however, cast-in-place bat condos received less use than the concrete panels (H.T. Harvey & Associates and HDR 2021).

Figure 7. Photo of recessed cast-in-place roost boxes from Caltrans Bat Mitigation: A Guide to Developing Feasible and Effective Solutions. (Photo used with permission from H.T. Harvey & Associates and HDR 2021)

The Kentucky Transportation Cabinet (KYTC) repaired a bridge used by a maternity colony of gray bats with box beams designed with 1.5-inch expansion joints to continue to provide habitat for the colony. The project was completed during winter when the bats were not present. The following summer, gray bats recolonized the new bridge with emergence counts estimating a colony size of 1,100 and the confirmation of pups.[8]

Bridges that are not designed with bat roosting characteristics in mind can be retrofitted with bat houses. In North Carolina, NCDOT installed large concrete slatted panels created by RD

[8] https://youtu.be/8Dxn5utleQw

Wildlife based in Arizona (Figure 8) under a bridge as mitigation for disturbing a bridge being used by gray bats. These structures were checked twice after installation in July and September, but no bats have used the roosts. However, with guidance from USFWS, these roosts were installed on a bridge that has had very little bat use prior to the installation (C. Manley, NCDOT, pers. comm.). Similar panels have worked well for Mexican free-tailed bats in Arizona.[9] The Texas Bat Abode is a design with many crevices that can house thousands of bats and has been modified to fit three different bridge designs. The Oregon Wedge is a design that has a single crevice that can house several hundred bats. The Oregon Wedge (Figure 9), which is "a plywood or concrete day roost box that is installed on the exterior of a transportation structure," has been designed for both bridges and culverts (Keeley and Tuttle 1999) and is one of the most effective add-on mitigation roosts for bridges that has housed Yuma myotis (*Myotis yumanensis*) and hundreds to thousands of Mexican free-tailed bats (H.T. Harvey & Associates and HDR 2021). In England, bat-friendly bricks and concrete bat boxes have been used to create roost habitat in bridges and new bridge designs are incorporating bat habitat into bridges for mitigation (Billington 1997). Several bat roost design plans were included in the Caltrans Bat Mitigation document (Appendix B; H.T. Harvey & Associates and HDR 2021).

Figure 8. Bat roosts installed on a bridge in Arizona as an example of those installed on a bridge in NC for gray bats. (Photo taken by Melina Zuniga and used with permission from Cronkite News)

[9] https://cronkitenews.azpbs.org/2018/03/06/officials-build-new-homes-bats-marana/

Figure 9. Concrete Oregon wedge style bat habitat with urine staining from Yuma myotis and Mexican free-tailed bats. (Photo used with permission from H.T. Harvey & Associates and HDR 2021)

3.5.3 Habitat Preservation

Preserving known roost habitat is the best way to reduce the impacts on bats using structures. Caltrans retained and reinforced bridge abutments of a replaced bridge instead of demolishing the entire bridge which allowed the bat colony to return to the abutments after construction (H.T. Harvey & Associates and HDR 2021). Caltrans has also temporarily excluded bats from bridges during bridge enhancement projects as opposed to permanent exclusion and habitat replacement. Bats were excluded from construction areas and allowed to return after construction was complete and exclusion was removed. In some cases, not all roosting habitat was excluded but only areas that were under construction. This allowed bats to utilize suitable habitat on the bridges while construction was taking place (H.T. Harvey & Associates and HDR 2021). This work was done in California where construction activities may take place year-round and where bats may not hibernate in bridges. How bats are using transportation structures should be considered when discussing temporary exclusion.

3.5.4 Research

In 2016 Ohio Department of Transportation (ODOT) discovered multiple abandoned railroad tunnels in eastern Ohio that were being used as hibernacula for multiple bat species. ODOT studied these tunnels and in 2019 installed a gate on one tunnel to protect it from human disturbance. As of 2018, ODOT was working to protect four additional abandoned railroad tunnels that were serving as bat hibernacula (Hill et al. 2019).

In 2015, NCDOT began a 5-year research project on northern long-eared bats to compensate for project effects. The goal was to determine the distribution of northern long-eared bats by tracking them to summer and winter roost trees. For the entirety of the project, 163 northern long-eared bats were captured and tracked to 229 roost trees (Jordan 2020).

Vermont Agency of Transportation (VTrans) replaced two bridges with a tunnel in 2020. VTrans installed multiple artificial bat roost structures of various types as mitigation and research to assess which structures bats prefer. Data was still being collected as of January 2021 (Lout 2022).

In the past, MoDOT entered formal consultation with USFWS for gray bats using a bridge in Missouri which resulted in funding for gating a cave for the species elsewhere in the state (B. McMurray, MoDOT, pers. comm.).

4 DATA GAPS

A considerable amount of work in the western part of the U.S. has produced copious amount of data concerning bat use of bridges and culverts. In addition to learning what structure characteristics bats prefer, making bridges more bat friendly has been a recent topic of interest. There has not been a collective effort to determine if western bridge types and roosting styles are comparable with those in the east. Data gaps in the east include:

1. Bridge and culvert material and size conducive to eastern bat species
2. Habitat needs surrounding a bridge or culvert roost
3. Differences among species for structure and habitat needs
4. Numbers of species using transportation structures
    a. Numbers of individuals of each species using transportation structures
5. Times of year transportation structures are used
    a. How this differs by species
    b. How this differs by climate (i.e., northern colder states vs. warmer southern states)
6. What artificial roost types work for eastern bat species

For all parts of the country, methods for deterring bats, either temporarily or permanently, from using structures is still in its infancy. In addition, more in-depth investigation into mitigation options both in the west and in the east is warranted.

5 FUTURE WORK

Although the topic of bats in transportation structures has been addressed multiple times in various states and countries, very little has been done in Missouri. MoDOT could coordinate with other agencies in the state that actively record bats when encountered on structures, such as the U.S. Army Corps of Engineers as part of their Missouri Bat Programmatic informal consultation. In addition, the U.S. Forest Service also conducts bat surveys and may have information on bats using bridges or culverts on federal lands. Below is a list of projects MoDOT could conduct on structures and properties they manage.

1) Conduct a robust survey of transportation structures in MO, targeting areas with a high likelihood of bat use.
    a. Develop bat survey form and/or electronic data form (e.g., within ESRI's Survey123) to record at least, but not limited to,

        i. Material and size of structure
        ii. Habitat surrounding the structure
        iii. Ambient temperature and time of day
        iv. Species use
            1. Sex and age of bats if possible
        v. Location of roosting (e.g., end of bridge but middle of width, dark zone, over water, on concrete or metal, etc.)
        vi. Cluster size
    b. Use variety of common tools to refine what works best
        i. Binoculars
        ii. Borescope
        iii. Thermal camera
2) Use data acquired from the robust survey described in number 1 to test the model created from the NCDOT ATLAS program (see Section 3.1)
    a. Requires a complete and thorough data set on the bridges in the state
        i. USFWS (2022d) recommends checking culverts within a certain size range (i.e., ≥ 2 ft tall and ≥ 23 ft long) for detecting the target species (Table 1).
    b. Model was built in the forested mountainous area of North Carolina so test on various habitat types, e.g., forested flat lands, agricultural patchwork land
3) At bridges with confirmed bat use, test multiple survey techniques to determine which is most effective and determine success rate for each technique
    a. Thermal camera with time of day and time of year as covariates
        i. Ambient temperature will be a factor as well as bat activity, which will change with reproductive period
        ii. Currently requires time consuming manual review
    b. Infrared camera
        i. Would require additional illuminator infrared equipment to light up sections of bridge effectively.
        ii. Currently requires time consuming manual review
    c. Active monitoring using acoustic detection with time of day and time of year as covariates
        i. May be able to get vocalizing bats during the day but more likely during emergence – calls may not be able to be identified to species
    d. Drone-mounted thermal camera to record bat emergence
        i. Can be used for bridges that are large or have bats roosting in areas inaccessible to humans
4) Testing a variety of exclusion and deterrent methods
    a. Exclusions
        i. One-way doors/escape tubes
        ii. Screens/plywood
        iii. Backer rod/sealant/expandable foam
    b. Deterrents
        i. Ultrasonic acoustic deterrents
        ii. Light
        iii. Noise

5) Test providing various artificial roosts for bats that are excluded from transportation structures
    a. Structure roosts (Oregon wedge) added to the transportation structure when bats are hibernating or prior to excluding from structure
    b. Standalone roosts (rocket boxes, bat condos, BrandenBark®) erected near the structure prior to excluding bats from structure

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APPENDIX A
ADDITIONAL TABLES

Non-target bat species in the United States documented using transportation structures.

State	Source	Structure Type	Roost Type/Notes
Antrozous pallidus			
AZ	Davis and Cockrum 1963	Highway bridges: open expansion joint	Maternity, summer male
AZ	Davis and Cockrum 1963	Railroad bridges	10 observed on one occasion in a railroad bridge
NM	Geluso and Mink 2009	Bridges	Infrequent
Choeronycteris mexicana			
AZ	Keeley and Tuttle 1999	Small, corrugated metal culverts	Day roosts
Corynorhinus rafinesquii			
multiple	Keeley and Tuttle 1999	Bridges	Maternity colony
GA	Lutsch et al. 2022	Culverts	Throughout year
LA	Ferrara and Leberg 2005b	Bridges	Summer mostly
LA	Lance et al. 2001	Bridges	Summer
MS	Martin et al. 2006	Culverts	
MS	Trousdale and Beckett 2004	Bridges	Maternity colony
NC	Felts and Webster 2003	Bridges	
NC	USFWS 2022d	Culvert	
SC	Bennett et al. 2008	Bridges	Maternity colony
Corynorhinus townsendii			
multiple	Keeley and Tuttle 1999	Bridges and culverts	Males in corrugated metal culverts
OR	Perlmeter 1995	Bridges	Night Roost
Eptesicus fuscus			
multiple	Keeley and Tuttle 1999	Bridges	21.5% of structures surveyed
AL	Bender et al. 2010	Culverts	Day Roosts
AZ	Davis and Cockrum 1963	Highway bridges: open expansion joint	Maternity
AZ	Davis and Cockrum 1963	Railroad bridges	Maternity

State	Source	Structure Type	Roost Type/Notes
IN	Cervone et al. 2016	Bridges	Maternity and winter
IN	Kiser et al. 2002	Bridges	Summer
LA	Ferrara and Leberg 2005b	Bridges	Year round
MO	B. McMurray, pers. com.	Bridge	Maternity
MS	Martin et al. 2006	Culverts	
MT	Hendricks et al. 2005b	Bridges	Maternity colony
NC	Etchison and Weber 2020	Bridges	Maternity
NC	USFWS 2022d	Culverts	
NM	Geluso and Mink 2009	Bridges	Infrequent
OR	Adam and Hayes 2000	Bridges	Maternity
OR	Perlmeter 1995	Bridges	Night Roost
S. IL	Feldhamer et al. 2003	Bridges	Summer
VT and ME	Civjan et al. 2017a,b	Bridge	
Lasionycteris noctivagans			
NM	Geluso and Mink 2009	Bridges	Infrequent
OR	Perlmeter 1995	Bridges	Night Roost
Lasiurus cinereus			
MT	Hendricks et al. 2005a	Bridges	1 w/pups (only record?)
Myotis austroriparius			
multiple	Keeley and Tuttle 1999	Bridges and culverts	Maternity roosts
AL	Bender et al. 2010	Culverts	Day roost
GA	Lutsch et al. 2022	Culverts	Throughout year
MS	Martin et al. 2006	Culverts	Year-round, most abundant in fall and winter
NC	Felts and Webster 2003	Bridges	
NC	USFWS 2022d	Culverts	
Myotis californicus			
OR	Adam and Hayes 2000	Bridges	Night roost
OR	Perlmeter 1995	Bridges	Night roost
NM	Geluso and Mink 2009	Bridges	Infrequent
Myotis ciliolabrum			
MT	Hendricks et al. 2005b	Bridges	Day roost
Myotis evotis			
OR	Adam and Hayes 2000	Bridges	Night roost
OR	Perlmeter 1995	Bridges	Night roost

State	Source	Structure Type	Roost Type/Notes
Myotis leibii			
AR	Blake Sasse - AGFC	Bridge	
NC	O'Keefe and Frazer 2007	Bridge	Maternity
WV	Alex Silvis - WVDNR	Bridge	
Myotis occultus			
NM	Geluso and Mink 2009	Bridges	Maternity
Myotis thysanodes			
OR	Adam and Hayes 2000	Bridges	Night roost
NM	Geluso and Mink 2009	Bridges	Infrequent
Myotis velifer			
multiple	Keeley and Tuttle 1999	Bridges	19% of structures surveyed, Infrequent
AZ	Davis and Cockrum 1963	Highway bridges: open end	Maternity
AZ	Davis and Cockrum 1963	Highway bridges: open expansion joint	Migration
TX	Keeley and Tuttle 1999	Culvert	Maternity
Myotis volans			
OR	Adam and Hayes 2000	Bridges	Maternity
OR	Perlmeter 1995	Bridges	Night roost
Myotis yumanensis			
AZ	Davis and Cockrum 1963	Highway bridges: open end	Maternity
NM	Geluso and Mink 2009	Bridges	Maternity
OR	Adam and Hayes 2000	Bridges	Maternity
OR	Perlmeter 1995	Bridges	Night roost
Nycticeius humeralis			
multiple	Keeley and Tuttle 1999	Bridges	Typically found in colonies of 2 to 200 individuals
Parastrellus hesperus			
multiple	Keeley and Tuttle 1999	Bridges	Found Roosting in the open between bridge beams

State	Source	Structure Type	Roost Type/Notes
Tadarida brasiliensis			
multiple	Keeley and Tuttle 1999	Bridges and culverts	Found in 26% of structures searched. TX, NM, AZ, and CA
AL	Bender et al. 2010	Culverts	Day roost
AZ	Davis and Cockrum 1963	Highway bridges: Open expansion joints	Migration
AZ	Davis and Cockrum 1963	Railroad bridges	Maternity and migration
NC	USFWS 2022d	Culverts	
NC	Etchison and Weber 2020	Bridges	Maternity
NM	Geluso and Mink 2009	Bridges	Maternity

APPENDIX B

STATE AND FEDERAL BAT SURVEY FORMS

APPENDIX C

ELECTRONIC RESOURCES

1) Georgia Department of Natural Resources and USFWS
   a. Bats and Transportation Structures Survey Training - https://www.youtube.com/watch?v=iuFwkT7q8Ws
   b. Georgia bats in bridges datasheet - https://www.dot.ga.gov/PartnerSmart/EnvironmentalProcedures/Ecology1/References/Georgia%20Bats%20in%20Bridges%20Datasheet%20-%20GADNR.pdf
2) U.S. Department of Transportation Federal Highway Administration: Environmental Review Toolkit - https://www.environment.fhwa.dot.gov/ESAWebTool/Site/ ibatNLEBBA.aspx#appb
3) CalTrans: Bat and Bridges Technical Bulletin - https://fdocuments.net/document/bat-and-bridges-technical-bulletin.html?page=1
4) AASHTO/National Cooperative Highway Research Program – Bridging the Gap Between Bats & Transportation Projects – A Manual of Best Management Practices for Bridges, Artificial Roosts, & Other Mitigation Approaches for North American Bats - https://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP25-25Task102BMPManual.pdf
5) Colorado DOT: Bat and Bridges Training - https://www.codot.gov/programs/environmental/wildlife/videos/bat-and-bridges-training
6) Iowa State University Institute for Transportation: Training Video for Bat Inspection at Bridges - https://www.youtube.com/watch?v=1h6mLDw2xKM
7) FHWA/Indiana State DOT/FRA: Preliminary Bat Inspection Guidelines for Bridges/Structures - https://www.nan.usace.army.mil/Portals/37/docs/regulatory/Nationwide%20Permit/FHWA%20Bridge%20Guidance%20APR%202015.pdf?ver=2019-05-20-123826-903
8) Weber et al. 2020 for NCDOT Research and Development: Distribution, Roosting and Foraging Ecology, and Migration Pathways for Gray Bats in Western North Carolina - https://wildlife.nres.illinois.edu/wp-content/uploads/2022/08/Appendix-B.-Manual.pdf