Artificial Bat Roost Mitigation Designs & Standardized Monitoring Criteria

Final Report

Prepared for

AASHTO Committee on Environment and Sustainability

Prepared by

Dale W. Sparks, David Tull
Ted Cable, Robert Tunison
Environmental Solutions & Innovations, Inc.
Cincinnati, Ohio

Robin Perez
Edward Samanns
Louis Berger US, Inc.
Morristown, New Jersey

The information contained in this report was prepared as part of NCHRP Project 25-25, Task 102, National Cooperative Highway Research Program.

Contractor's Final Report
June 2019

Acknowledgements

This study was conducted for the AASHTO Committee on Environment and Sustainability, with funding provided through the National Cooperative Highway Research Program (NCHRP) Project 25-25, Task 102, Artificial Bat Roost Mitigation Designs and Standardized Monitoring Criteria. The NCHRP is supported by annual voluntary contributions from the state Departments of Transportation. Project 25-25 is intended to fund quick response studies on behalf of the Committee on Environment and Sustainability. The report was prepared by Dale W. Sparks, David Tull, Ted Cable, and Robert Tunison of Environmental Solutions & Innovations, Inc; and Robin Perez and Edward Sammans of Louis Berger US, Inc. The work was guided by a technical working group that included:

- Timothy Hill, Ohio Department of Transportation
- Amy Bailey, California Department of Transportation
- Kris J. Gade, Arizona Department of Transportation
- Christine (Chris) Maguire, Oregon Department of Transportation
- Jeff S. Peterson Colorado Department of Transportation
- Mary Kay Solberg, Iowa Department of Transportation
- Kevin Moody, FHWA (Liaison)

The project was managed by Ann Hartell NCHRP Senior Program Officer.

Executive Summary

This report was developed as a summary of available data related to the use of bridges and other artificial roosts by bats and the potential role of bridges and artificial roosts as mitigation when transportation infrastructure negatively impacts bats. In addition to impacts from transportation projects, bat populations face other challenges including habitat loss, direct mortality at wind energy sites, and the fatal disease White-nose Syndrome (WNS).

A literature review of 169 documents was completed, ranging from published abstracts to technical reports to publications in the primary literature. Documents reviewed included 65 papers where bats roosted in bridges, 24 where bats roosted in pipes and culverts, 50 papers where bats used artificial roosts designed for their benefit, and 51 papers where bats roosted in buildings or other anthropogenic habitats, including multiple cases of bats roosting on utility poles. Use of artificial roosts by bats is thus a well-known and nearly universal phenomenon.

The research team developed and distributed a survey regarding bat usage of highway infrastructure to 90 recipients (with at least one recipient in each state), and received 62 responses. Bats were reported in bridges throughout the U.S., but reported culvert-use by bats included only culverts that were very long and resembled caves. Efforts to mitigate impacts to bats vary by state, but include developing bat-friendly bridge designs, retrofitting bridges with artificial roosts, use of stand-alone bat roosts, and preservation, restoration, and enhancement of natural habitat. Notably, the definition of successful mitigation varied among wildlife agencies who focused on use by bats or acres of habitat protected. Transportation agencies tended to view a mitigation effort that facilitated project completion as a success.

Comparisons of bridge designs were completed by leveraging a nationwide data set obtained from the literature review and by using data collected by the Minnesota Department of Transportation during structural inspection of bridges. Bats are attracted to concrete bridge designs that provide access to roosting habitat (cracks, crevices, and protected open space) such as I-beam, T-beam, box beam, or channel beam designs. The Minnesota data revealed that bats preferentially used bridges that shared the following features:

- bridges with prestressed or precast concrete beams;
- span bridges with a concrete, cast-in-place, deck; and
- bridges that crossed a waterway.

The combination of attributes accounted for 62 percent (%) of bridges where bats were found, but represented only 7.5% of the total sample. Both data sets indicate bridges can provide successful mitigation when large bridges cross water in landscapes that are otherwise suitable for bats. The addition of supplemental roosting structures can also attract bats.

Three recent reviews of stand-alone artificial roosts indicate a wide variety of roost designs are available and attracted bats. The most successful designs target specific roosting needs of target species of bats and incorporate an understanding of thermal conditions favorable to roosting bats. As a rule of thumb, bat maternity colonies (mothers and their dependent young) are attracted to roosts with temperatures between 80° and 100° Fahrenheit (F; 26-38˚ C) whereas adult male and non-reproductive female bats will use structures with cooler temperatures. Temperatures greater than 113° F (45˚ C) are fatal. Relatively small changes to the size, type, color, and location of an artificial roost can result in a roost that is too cool for maternity colonies or becomes lethally hot in summer. Efforts aimed at protecting habitat generalist species are likely to succeed with most available artificial roosts. Efforts aimed at attracting more habitat specialized species should carefully consider the ecological needs of the species. In most cases, obtaining outside assistance from a bat biologist is an important consideration. In all cases, an artificial roost should be selected that is appropriate for the goals of mitigation.

Finally, using artificial roosts as a means of mitigating impacts to bats should be considered a subset of larger mitigation efforts. Artificial roosts can replace roosting habitat, but is of little value when foraging or drinking habitat is the limiting resource for these populations.

Results of this study were used to generate a Best Management Practices Manual, designed to synthesize the technical analyses contained in this document and produce a concise tool for use by transportation professionals responsible for addressing interactions between transportation projects and relevant environmental regulations. The manual's primary objective is to provide transportation professionals with information on how to detect the presence of bats along with strategies to avoid, minimize, and mitigate impacts to bats from transportation projects.

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1.0 Introduction

Cave-hibernating bats throughout North America are enduring a period of unprecedented decline associated with the fungal disease White-Nose Syndrome (WNS). Other challenges facing bats include mortality at wind energy facilities, direct persecution, and loss of habitat. In response to concern over declining bat populations, there is an increased focus on protecting bats and their habitats as well as finding ways to mitigate for unavoidable impacts. Declining bat populations also led to increased focus on the need to understand how bats interact with transportation infrastructure – especially bridges.

The presence of bats in bridges represents an area of on-going academic research for more than 70 years. Concerns are growing as transportation, natural resource, and wildlife agencies strive to understand the value of bridges as bat habitat and the long-term value of bridges as potentially mitigating declining bat populations affected by WNS.

This document provides transportation, natural resource, and wildlife agencies a comprehensive assessment of the value of bridges as bat habitat and assessment of techniques transportation agencies can implement to mitigate impacts of transportation infrastructure on bats. This report provides an overview of available literature on the use of artificial roosts (especially bridges) by bats, and serves as a baseline for subsequent studies. The first step of document development included a questionnaire containing information on how literature was applied to interactions between bats and transportation infrastructure. The questionnaire also provided a means for identifying and accessing unpublished data sets focused on bat use of bridges and on applying bat mitigation procedures.

2.0 Literature Review

A literature review was conducted to develop an annotated bibliography of publications on the use of bridges, culverts, and artificial bat roosts by different bat species with a focus on those native to North America. Information gathered from the literature search was used to support development of a questionnaire distributed to DOTs and others working at the intersection of transportation and ecology (Section 3.0) and provided a theoretical basis for statistical analysis. Data from the literature review and questionnaire were used to support analyses of bridge and culvert types most likely to serve as roosts for bats, determine what elements make an artificial roost successful or unsuccessful at mitigating impacts of transportation infrastructure on bats, and inform development of a Best Design Practices Manual, a document developed in parallel with the current, more technical report.

2.1 Methods

A three-step process identified potentially relevant literature: 1) begin with sources known to the Team, 2) complete a typical library-based literature search, and 3) incorporate any new resources discovered during work on subsequent portions of the project. Each step is detailed in the following sections.

2.1.1 Step 1: Review Resources Already in Possession

The first step included an in-house data base (maintained by Environmental Solutions & Innovations [ESI]) search for publications on bats and mitigation.

2.1.2 Step 2: Use of Online Search Engines to Locate Additional Papers

The second step in the literature review included a search of the following databases for records of publications about bats using artificial roosts or bridges: Google Scholar, Research Gate, AGRIS, Biological Abstracts, Proquest, Ebsco Host, JSTOR, PubMed, TRIS database, ScienceDirect, and Science.gov. Searches were completed based on the following criteria:

- Key Words: bats (along with common genera such as *Eptesicus*, *Myotis*, and *Corynorhinus*) in combination with the following terms, roosts, artificial roosts, maternity roosts, hibernacula, bat boxes, and bridges;
- Author Names; and
- Indexed Citations (e.g., checking the bibliography of each paper for additional citations and checking on-line resources for newer papers that in-turn cited a paper).

2.1.3 Step 3: Incorporate Publications Detected During Subsequent Phases of the Project

The final step incorporated material compiled during later phases of the project and included documents published during the project and those received from external reviewers including the research panel.

Once assembled, literature was summarized in tabular form (Table 1) and presents each record by the information of greatest use to a practitioner seeking information on a particular type of artificial roost, or by a particular species. Bibliographic information for locating the publication through either the complete citation (at the end of the section) or via an internet search is also provided.

Table 1. Summary of published data on bats and the use of artificial roosts.

		Type of Bat				Contained Data on Bats Roosting in					
Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Adam and Hayes 2000)	Use of bridges as night roosts by bats in the Oregon coast range	*Corynorhinus townsendii, Eptesicus fuscus, Myotis californicus, Myotis evotis, Myotis lucifugus, Myotis thysanodes, Myotis volans, Myotis yumanensis*	X	X		X					
(Adams et al. 2015)	Success of BrandenBark, an artificial roost structure designed for use by Indiana bats *(Myotis sodalis*).	*Perimyotis subflavus, Myotis lucifugus, Myotis septentrionalis, Myotis sodalis Eptesicus fuscus, Nycticeius humeralis*	X	X	X				X		
(Agnelli et al. 2011)	Artificial roosts for bats: education and research. The "Be a bat's friend" project of the Natural History Museum of the University of Florence	All Species in Italy							X		
(Agosta 2002)	Habitat use, diet and roost selection by the big brown bat (*Eptesicus fuscus*) in North America: a case for conserving an abundant species	*Eptesicus fuscus*	X		X				X	X	
(Allen et al. 2009b)	Roosting ecology and variation in adaptive and innate immune system function in the Brazilian free-tailed bat (*Tadarida brasiliensis*)	*Tadarida brasiliensis*	X		X	X					
(Allen et al. 2011)	Variation in physiological stress between bridge- and cave-roosting Brazilian free-tailed bats	*Tadarida brasilensis*	X		X	X					
(Allen et al. 2009a)	Birth size and postnatal growth in cave and bridge roosting Brazilian free-tailed bats	*Tadarida brasiliensis*	X		X	X					

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Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Amorim et al. 2013)	Bridges over the troubled conservation of Iberian bats	*Tadarida teniotis, Rhinolophus ferrumequinum, Rhinolophus hipposideros, Myotis escalerai, Myotis myotis, Myotis daubentonii, Pipistrellus pipistrellus, Pipistrellus pygmaeus, Hypsugo savii, Eptsicus serotinus, Eptesicus isabellinus, Nyctalus leisleri, Nyctalus lasiopterus, Barbastella barbastellus, Plecotus auritus, Plecotus austriacus*		X	X	X					
(Arnett and Hayes 2000)	Bat use of roosting boxes installed under flat-bottom bridges in Western Oregon	*Eptesicus fuscus*	X		X	X			X		
(Barclay and Cash 1985)	A non-commensal maternity roost of the little brown bat (*Myotis lucifugus*)	*Myotis lucifugus*	X		X					X	
(Barclay et al. 1980)	Comparison of methods used for controlling bats in buildings	*Eptesicus fuscus Myotis lucifugus*	X		X				X		
(Bartonicka and Řehák 2007)	Influence of the microclimate of bat boxes on their occupation by the soprano pipistrelle *Pipistrellus pygmaeus*: possible cause of roost switching	*Pipistrellus pygmaeus*			X				X		
(Bartonička and Růžičková 2012)	Bat bugs (*Cimex pipistrelli*) and their impact on non-dwelling bats	*Myotis myotis*		X						X	
(BCI 2011)	Creating bat-friendly bridges and culverts Pages 191-193 *in* Bat conservation and management workshop: Course booklet	All species in Arizona	X	X	X	X		X			
(Bektas et al. 2018)	Most likely bridges as roosting habitat for bats: Study for Iowa.	All species in Iowa	X	X	X	X					X
(Benedict et al. 2017)	Use of Buildings by Indiana Bats (Myotis sodalis) and Other Bats in South-central Iowa	*Eptesicus fuscus, Myotis lucifugus, Myotis sodalis*	X	X	X					X	
(Bennett and Zurcher 2013)	When corridors collide: Road related disturbance in commuting bats	*Eptesicus fuscus, Lasiurus borealis, Myotis lucifugus and Lasiurus cinereus*	X	X							X
(Bennett 2005)	Use and selection of highway bridges by Rafinesque's big-eared bats in South Carolina	*Corynorhinus rafinesquii*	X	X		X					

Citation	Title	Focal Species	Type of Bat: Natives to US?	Listed	Non-Listed	Contained Data on Bats Roosting in: Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Bennett et al. 2008)	Use and selection of bridges as day roosts by Rafinesque's big-eared bats	*Corynorhinus rafinesquii*	X	X		X					
(Berkova et al. 2014)	Selection of buildings as maternity roosts by greater mouse-eared bats (*Myotis myotis*)	*Myotis myotis*								X	
(Betts 2010)	Thermoregulatory mechanisms used in a maternity colony of Townsend's big-eared bats in northeastern Oregon	*Corynorhinus townsendii*	X	X						X	
(Brack and Whitaker 2006)	The Indiana Myotis (*Myotis sodalis*) on an anthropogenic landscape: Newport Chemical Depot, Vermillion County, Indiana.	*Myotis sodalis*	X	X						X	X
(Baker et al. 1968)	A three-year study of two breeding colonies of the big brown bat, *Eptesicus fuscus*	*Eptesicus fuscus*	X		X					X	
(Brittingham and Williams 2000)	Bat boxes as alternative roosts for displaced bat maternity colonies	*Eptesicus fuscus, Myotis lucifugus*	X		X				X		
(Brokaw and Szewczak 2015)	*Yuma myotis* social calls attract bats to artificial roosts	*Myotis yumanensis, Tadarida brasiliensis*	X	X					X		
(Buchler and Childs 1982)	Use of post-sunset glow as an orientation cue by big brown bats	*Eptesicus fuscus*	X		X					X	
(Butchkoski 2009)	Summer bat concentration survey (Annual report for 1 July 2008 to 30 June 2009)	*Multiple Species, Myotis lucifugus, Myotis sodalis*	X	X	X	X		X		X	
(Butchkoski 2010)	Summer bat concentration survey/Appalachian bat count (Annual report for 1 January 2009 to 31 December 2009).	*Multiple Species, Myotis lucifugus, Myotis sodalis*	X	X	X	X		X		X	
(Butchkoski and Hassinger 2002)	Ecology of a maternity colony roosting in a building.	*Myotis lucifugus, Myotis sodalis*	X	X	X				X	X	
(Butchkoski et al. 2002)	Summer bat concentration survey (Annual report for 1 July 2001 to 30 June 2002)	*Multiple Species, Myotis lucifugus, Myotis sodalis*	X	X	X			X		X	
(Carter et al. 2001)	Notes on summer roosting of Indiana bats	*Myotis sodalis, Myotis austroriparious, Myotis lucifugus*	X	X	X				X		
(Celuch and Sevcik 2008)	Road bridges as a roosts for Noctules (*Nyctalus noctula*) and other bat species in Slovakia (Chiroptera: Vespertilionidae)	*Nyctalus noctula, Myotis myotis and Myotis daubentonii*		X		X					

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Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Cervone and Yeager 2016)	Bats under an Indiana bridge	*Myotis sodalis, M. grisescens, Myotis lucifugus, Eptesicus fuscus, Perimyotis subflavus*	X	X		X					X
(Ciechanowski 2005)	Utilization of artificial shelters by bats (Chiroptera) in three different types of forest	*Pipistrellus nathusii, Plecotus auritus*							X		
(Chambers et al. 2002)	Use of artificial roosts by forest dwelling bats in northern Arizona	*Myotis evotis, Myotis volans, Myotis thysanodes, I. phyllotis, E. fusucus*	X		X				X		
(Chenger 2003)	Iowa Army Ammunition Plant 2003 Indiana bat investigations.	*Eptesicus fuscus, Myotis lucifugus, Myotis sodalis*	X	X						X	
(Civjan et al. 2016)	Bats roosting in bridges: details and results from a New England project	All species in New England	X	X		X					
(Cleveland and Jackson 2013)	Environmental factors influencing the status and management of bats under Georgia (USA) bridges	All species in Georgia	X	X	X	X					
(Coltrain et al. 2003)	Local schools as partners in Bat research	All species near Marrow, Georgia	X		X				X		
(Curry and Farrell 2016)	Summer roosting ecology of *Myotis septentrionalis* in the North Atlantic Coastal plain	*Myotis septentrionalis*	X	X						X	
(Davis and Cockrum 1963)	Bridges utilized as day-roosts by bats	*Tadarida brasiliensis, Antrozous pallidus, Eptesicus fuscus, Myotis velifer, Myotis melanorhinus, Myotis yumanensis, Myotis californicus,*	X	X		X					
(Dey 2009)	Roost selection, roosting fidelity, and activity patterns of female Indiana bats (*Myotis sodalis*) in northern Missouri	*Myotis lucifugus, Myotis sodalis*	X	X	X					X	
(Diamond and Diamond 2003)	Bat use of box style bridges on highway systems in Beaver, Iron and Washington counties of southwestern Utah	All species in Utah	X	X		X					
(Diamond et al. 2015)	Population characteristics of big brown bat and Arizona Myotis using artificial roosting structures in northern Arizona	*Eptesicus fuscus, Myotis occultus*	X	X	X				X		
(Dickerman et al. 1981)	Notes on Bats from the Pacific Lowlands of Guatemala	*Saccopteryx bilineata centra. Macrophyllum macrophyllum, Glossophaga, Myotis nigricans nigricans, Molossus molossus lambi,*			X	X		X		X	

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(Dillingham et al. 2003)	Two environmental factors that influence usage of bat houses in managed forest of Southwest Oregon	Unknown (identifications were not attempted)	X		X				X		
(Dooley et al. 1976)	Ectoparasites from bats in extreme west Texas and south-central New Mexico	*Myotis californicus, Parastrellus hesperus, Antrozous pallidus, Eptesicus fuscus, Tadarida brasiliensis*	X		X		X	X		X	
(Ellison et al. 2007)	Factors influencing movement probabilities of big brown bats (*Eptesicus fuscus*) in buildings	*Eptesicus fuscus*	X		X					X	
(ESI 2006)	2005 Summer mist net and radio-telemetry surveys for the federally-endangered Indiana bat for Phase 1 of the Millennium Gas Pipeline project, Orange and Rockland counties, New York.	*Myotis lucifugus, Myotis sodalis*	X	X	X					X	
(Fagan et al. 2016)	Roost selection by synanthropic bats in buildings of Great Smoky Mountains National Park	*Corynorhinus rafinesquii, Eptesicus fuscus, Myotis leibii, Myotis lucifugus*	X	X						X	
(Fagan et al. 2018)	Roost selection by bats in buildings, Great Smoky Mountains National Park	*Corynorhinus rafinesquii, Eptesicus fuscus, Myotis lucifugus, Myotis septentrionalis, Myotis leibii*	X	X	X					X	X
(Farrell Sparks et al. 2004)	Utility pole used as a roost by a Northern Myotis, *Myotis septentrionalis*	*Myotis septentrionalis*	X	X						X	
(Feldhamer et al. 2003)	Use of bridges as day roosts by bats in southern Illinois	*Eptesicus fuscus, Perimyotis subflavus, Myotis lucifugus, Myotis septentrionalis*	X	X	X	X					
(Fenton 1997)	Science and the conservation of bats	Multiple Species	X	X	X	X	X		X	X	X
(Ferrara and Leberg 2003)	Seasonal use of bridge roosts in Louisiana	*Corynorhinus rafinesquii, Eptesicus fuscus, Perimyotis subflavus, Myotis sp.*	X	X		X					
(Ferrara and Leberg 2005a)	Characteristics of positions selected by day-roosting bats under bridges in Louisiana	*Corynorhinus rafinesquii, Perimyotis subflavus, Eptesicus fuscus*	X	X	X	X					
(Ferrara and Leberg 2005b)	Influences of investigator disturbance and temporal variation on surveys of bats roosting under bridges	*Corynorhinus rafinesquii, Perimyotis subflavus, Eptesicus fuscus*	X	X	X	X					
(Flaquer et al. 2005)	The value of bat-boxes in the conservation of pipistrellus pygmaeus in wetland rice paddies	*Pipistrellus pygmaeus*			X				X		

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Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Flaquer et al. 2007)	Comparison of sampling methods for inventory of bat communities	*Rhinolophus ferrumequinum, Rhinolophus hipposideros, Rhinolophus euryale, Myotis myotis, Myotis blythii, Myotis nattereri, Myotis emarginatus, Myotis daubentonii, Myotis capaccinii, Pipistrellus pipistrellus, Pipistrellus pygmaeus, Pipistrellus nathusii, kuhlii, Eptesicus serotinus, Plecotus austriacus, Miniopterus schreibersii*		X	X		X		X	X	
(Fraze and Wilkins 1990)	Patterns of use of man-made roosts by *Tadarida brasiliensis mexicana* in Texas	*Tadarida brasiliensis*	X		X	X		X			
(Gates et al. 1984)	Status of cave-dwelling bats in Maryland: Importance of marginal habitats	*Myotis lucifugus, Myotis septentrionalis, Myotis sodalis, Myotis leibii, Perimyotis subflavus, Eptesicus fuscus*	X	X			X	X			
(Gehrt and Chelsvig 2004)	Species specific patterns of bat activity in an urban landscape	*Eptesicus fuscus, L asionycteris noctivagans, Lasiurus borealis, Lasiurus cinereus, Perimyotis subflavus, Myotis*	X	X							X
(Gaisler et al. 2009)	Bat casualties by road traffic (Brno-Vienna).	*Myotis brandtii, Myotisalcathoe, Myotis emarginatus, Myotis nattereri Myotis bechsteinii, Myotis daubentonii, Myotis mystacinus/brandti, Eptesicus serotinus Nyctalus noctula, Nyctalus leisler, Pipistrelus pipistrellus, Pipistrellus pygmaeus, Pipistrellus nathusis*	X	X	X						X
(Geluso and Mink 2009)	Use of bridges by bats (Mammalia: Chiroptera) in Rio Grande Valley, New Mexico	*Myotis lucifugus occultus, Myotis yumanensis, Tadarida braziliensis, Antrozous pallidus, Eptesicus fuscus, Lasionycteris noctivagans, Myotis californicus, Myotis thysanodes*	X	X	X	X					
(Geluso et al. 2018)	Night-roosting behaviors for the northern long-eared Myotis (*Myotis septentrionalis*) under a bridge revealed by time-lapse photography	*Myotis septentrionalis*	X	X		X					
(Goehring 1954)	*Pipistrellus subflavus obscurus, Myotis keenii*, and *Eptesicus fuscus fuscus*	*Perimyotis subflavus, Myotis septentrionalis, Eptesicus fuscus*	X	X	X			X			

Citation	Title	Focal Species	Type of Bat			Contained Data on Bats Roosting in					Information on Bats and Roads
			Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	
	hibernating in a storm sewer in central Minnesota										
(Goldingay and Stevens 2009)	Use of artificial tree hollows by Australian birds and bats	*Chalinolobus gouldii, Vespadelus darlingtoni*			X				X		
(Gore and Studenroth 2005)	Status and management of bats roosting in bridges in Florida	*Tadarida brasiliensis, Eptisicus fuscus, Myotis austroriparius, Nycticeius humeralis*	X		X	X					
(Griffiths et al. 2017a)	Bat boxes are not a silver bullet conservation tool	*Chalinolobus gouldii, Chalinolobus morio, Scotorepens orion, Vespadelus darlingtoni, Vespadelus regulus, Vespadelus vulturnus, Austronomus australis, Mormopterus planiceps*							X		
(Griffiths et al. 2017b)	Surface reflectance drives nest box temperature profiles and thermal suitability for target wildlife	Unknown (identifications were not attempted)							X		
(Gumbert et al. 2013)	Artificial bark designed for roost use by Indiana bats (Myotis sodalis).	*Myotis lucifugus, Myotis septentrionalis, Myotis sodalis*	X	X	X				X		
(Hall 1962)	A life history and taxonomic study of the Indiana bat, *Myotis sodalis*	*Myotis sodalis*	X	X						X	
(Hall 1963)	Notes on *Plecotus refinesquii* in central Kentucky	*Corynorhinus rafinesquii*	X	X						X	
(Hamilton and Barclay 1994)	Patterns of daily torpor and day-roost selection by male and female big brown bats *(Eptesicus fuscus*)	*Eptesicus fuscus*	X		X					X	
(Harvey 2002)	Status and ecology in the southeastern United States	*Myotis sodalis*	X	X						X	
(Hayes et al. 2011)	Hibernacula selection by Townsend's big-eared bat in southwestern Colorado	*Corynorhinus townsendii*	X	X			X				
(Hendricks et al. 2004)	Notable roosts for the Indiana bat (*Myotis sodalis*).	*Myotis sodalis*	X	X						X	
(Hendricks et al. 2005a)	Use of a bridge for day roosting by the Hoary bat, *Lasiurus cinereus*	*Lasiurus cinereus*	X	X	X	X					
(Hendricks et al. 2005b)	Bat use of highway bridges in south-central Montana	*Lasiurus cinereus, Myotis lucifugus, Eptesicus fuscus, Myotis ciliolabrum*	X	X	X	X					

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Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other		
(Hirshfeld et al. 1977)	Night roosting behavior in four species of desert bats	*Myotis californicus, Parastrellus hesperus, Antrozous pallidus, Tadarida brasiliensis*	X	X		X				X		
(Hoeh and O'Keefe 2015)	Social behavior of Indiana bats selecting among artificial roosts	*Myotis sodalis*	X	X					X			
(Hoeh et al. 2018)	In artificial roost comparison, bats show preference for rocket box style.	*Myotis sodalis*, *Myotis septentrionalis*, *Eptesicus fuscus*	X	X					X			
(Horn and Kunz 2008)	Analyzing NEXRAD doppler radar images to assess nightly dispersal patterns and population trends in Brazilian free-tailed bats (*Tadarida brasiliensis*)	*Tadarida brasiliensis*	X		X	X						
(Irvine and Bender 1995)	Initial results from bat roosting boxes at Organ Pipes National Park	*Austronomus australis, Chalinolobus gouldii, Chalinolobus morio, Nyctophilus geoffroyi, Vespadelus darlingtoni, Vespadelus regulus, Vespadelus vulturnus*			X				X			
(Jackson et al. 1982)	Cave myotis roosting in barn swallow nests	*Myotis velifer*	X	X				X				
(Jenkins et al. 1998)	Roost selection in the pipistrelle bat, *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae), in northern Scotland	*Pipistrellus pipistrellus*			X				X			
(Johnston 2005)	Recreating battered bat roosts: planning and perseverance pay off at a California bridge	*Eptesicus fuscus, Myotis yumanensis Tadarida brasiliensis*	X	X	X	X			X			

		Type of Bat				Contained Data on Bats Roosting in					
Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Johnston et al. 2004)	California bat mitigation techniques, solutions, and effectiveness	*Antrozous pallidus, Choeronycteris mexicana, Corynorhinus townsendii, Eptesicus fuscus, Euderma maculatum, Eumops perotis, Lasionycteris noctivagans, Lasiurus blossevillii, Lasiurus cinereus, Lasiurus xanthinus, Leptonycteris curasoae, Macrotus californicus, Myotis californicus, Myotis ciliolabrum, Myotis evotis, Myotis lucifugus, Myotis occultus, Myotis thysanodes, Myotis velifer, Myotis volans, Myotis yumanensis, Nyctinomops femorosaccus, Nyctinomops macrotis, Parastrellus hesperus Tadarida brasiliensis*	X	X	X	X	X		X	X	X
(Johnson et al. 2012)	Social networks of Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) in bottomland hardwood forests	*Corynorhinus rafinesquii*	X	X		X					
(Johnson et al. 2016)	Status and summer roost sites of threatened *Myotis septentrionalis* on the island of Martha's vineyard	*Myotis septentrionalis*	X	X						X	
(Johnson et al. 2002)	Gray bat night-roosting under bridges	*Myotis grisescens*	X	X		X					
(Kaarakka 2016)	Roost monitoring report.	*Perimyotis subflavus, Myotis lucifugus, Myotis septentrionalis Eptesicus fuscus*	X	X		X			X	X	
(Kaarakka 2017)	Roost monitoring report	*Perimyotis subflavus, Myotis lucifugus, Eptesicus fuscus*	X	X		X			X	X	
(Karsk et al. 2018)	Bat roosts in bridges: Assessing Illinois bridges for bat use	*Myotis sodalist, Myotis grisescens,Myotis septentrionalis, Myotis austroriparius, Corynorhinus rafinesquii,* and all other Illinois bats	X	X	X	X		X			
(Kasprzyk and Ruczynski 2007)	The structure of bat communities roosting in bird nest boxes in two pine monocultures in Poland	*Myotis daubentonii, Nyctalus nactula, Myotis dasycneme. Pipistrellus pipistrellus, Plecotus auritus*		X	X				X		
(Kiser et al. 2002)	Use of concrete bridges as night roosts	*Perimyotis subflavus, Myotis lucifugus, Myotis septentrionalis, Myotis sodalis Eptesicus fuscus*	X	X	X	X					X

Citation	Title	Focal Species	Type of Bat			Contained Data on Bats Roosting in						Information on Bats and Roads
			Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other		
(Keeley and Tuttle 1999)	Bats in American bridges	*Antrozous pallidus, Corynorhinus rafinesquii, Corynorhinus townsendii. Eptesicus fuscus, Myotis austroriparious, Myotis californicus, Myotis ciliolabrum, Myotis grisescens, Myotis evotis, Myotis lucifgus, Myotis septentrionalis, Myotis thysanodes, Myotis leibii, Myotis velifer, Myotis volans, Myotis yumanensis, Nycticeius humeralis, Parastrellus hesperus, Perimyotis subflavus, Tadarida brasiliensis*	X	X	X	X		X	X			X
(Keeley and Keeley 2004)	The Mating system of *Tadarida brasiliensis* (Chiroptera: Molossidae) in a large highway bridge colony	*Tadarida brasiliensis*	X		X	X						
(Keeley 2007)	Bats and bridges. An evaluation of selected bridges in Laois and Offaly	*Plecotis auritus, Myotis nattereri, Myotis daubentonii*			X	X						
(Kerth et al. 2000)	Day roost selection in female Bechstein's bats (*Myotis bechsteinii*) a field experiment to determine the influence of roost temperature	*Myotis bechsteinii*		X					X			
(Krebbs 2003)	Updates on four bat research projects in southern Arizona	*Leptonycteris curasoae*	X	X					X			
(Krutzsch 1946)	Some observation on the big brown bat in San Diego County California	*Eptesicus fuscus*	X		X		X			X		
(Kuenzi et al. 1999)	Bat distribution and hibernacula use in west central Nevada	*Myotis melanorhinus, Parastrellus hesperus, Myotis californicus, Corynorhinus townsendii,*	X		X		X					
(Kunz et al. 1977)	Mortality of little brown bats following multiple pesticide applications	*Myotis lucifugus*	X		X					X		
(Laidlaw and Fenton 1971)	Control of nursery colony populations of bats by artificial light	*Myotis lucifugus, Eptesicus fuscus*	X		X					X		
(Lance et al. 2001)	Day roost selection by Rafinesque's big-eared btas (*Corynorhinus rafinesquii*) in Louisiana forests	*Corynorhinus rafinesquii*	X	X		X						

Citation	Title	Focal Species	Type of Bat: Natives to US?	Type of Bat: Listed	Type of Bat: Non-Listed	Contained Data on Bats Roosting in: Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Lausen and Barclay 2006)	Benefits of living in a building: Big brown bats (*Eptesicus fuscus*) in rocks versus buildings	*Eptesicus fuscus*	X		X					X	
(Lewis 1994)	Night roosting ecology of pallid bats (*Antrozous pallidus*) in Oregon	*Antrozous pallidus*	X		X	X				X	
(Loeb and O'Keefe 2006)	Habitat use by forest bats in South Carolina in relation to local, stand, and landscape characteristics	*Eptesicus fuscus, L. borealis, Perimyotis subflavus, Myotis septentrionalis*	X	X							X
(Long 2003)	California bat house research project	*Antrozous pallidus, Tadarida brasiliensis, Myotis sp, Eptesicus fuscus*	X		X				X		
(Long et al. 2006)	Well-placed bat houses can attract bats to Central Valley farms	*Tadarida. brasiliensis, Antrozous pallidus, Eptesicus fuscus, Myotis californicus, Myotis yumanensis*	X	X					X		
(Mann et al. 2002)	Effects of cave tours on breeding *Myotis velifer*	*Myotis velifer*	X		X		X				
(Martin et al. 2016)	The southeastern bat in Mississippi	*Myotis austroriparius*	X	X				X			
(Martinez et al. 2015)	Annual and seasonal fluctuations in roost use by *Tadarida brasiliensis* in a highway overpass, San Angelo, Texas	*Tadarida brasiliensis*	X		X	X					
(McDonnell 2001)	Use of bridges as day roosts by bats in the North Carolina coastal plain	*Corynorhinus rafinesquii, Perimyotis subflavus, Myotis austroriparius*	X	X		X		X			
(Mering and Chambers 2012)	Artificial roosts for tree-roosting bats in northern Arizona	*Eptesicus fuscus, Myotis evotis, Myotis thysanodes, Myotis volans, Myotis lucifugus occultus*	X	X					X		
(Mering and Chambers 2014)	Thinking outside of the box: A review of artificial roosts for bats	*Eptesicus fuscus, Myotis evotis, Myotis thysanodes, Myotis volans, Myotis lucifugus occultus*	X	X					X		
(Mohr 1942)	Bat tagging in Pennsylvania turnpike tunnels	*Eptesicus fuscus, Perimyotis subflavus, Myotis lucifugus, Myotis sodalis*	X	X				X			
(Mumford and Cope 1958)	Summer records of *Myotis sodalis* in Indiana	*Myotis sodalis*	X	X						X	
(Nagel and Gates 2016)	Abandoned railroad tunnels serving as hibernacula: a refuge for bats in a white-nose syndrome world (BRN volume 57 pg 94)	*Myotis. lucifgus, Myotis septentrionalis, Perimyotis subflavus, Eptesicus fuscus, Myotis leibii*	X	X				X			

			Type of Bat			Contained Data on Bats Roosting in						
Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(NDOR 2016)	Final report: bridge and culvert use by bats in Nebraska	*Myotis septentrionalis*	X	X		X		X			
(Neilson and Fenton 1994)	Responses of little brown myotis to exclusion and to bat houses	*Myotis lucifugus*	X	X					X		
(O'Keefe and LaVoie 2011)	Maternity colony of eastern small-footed myotis (*Myotis leibii*) in a historic building	*Myotis leibii*	X	X						X	
(Ober et al. 2015)	Conservation implications of some unusual characteristics of the endangered Florida bonneted bat	*Eumops floridanus*	X	X					X		
(ODOT 2016)	Bridge Design and Drafting Manual	All Species in Oregon	X	X	X	X					
(Park et al. 1996)	Assortative roosting in the two phonic types of *Pipistrellus pipistrellus* during the mating season	*Pipistrellus pipistrellus*			X				X		
(Patriquin et al. 2015)	Use of an urban park by big brown bats	*Eptesicus.fuscus*	X		X					X	
(Patterson et al. 2007)	Roosting habits of bats affects their parasitism by bat flies (Diptera: Streblidae)	130 Species Captured in Venezuela	X		X	X	X	X	X	X	
(Perlmeter 1996)	Bats and bridges: Patterns of night roost activity in the Willamette National Forest	*Myotis lucifugus, Myotis volans*	X	X		X					
(Perry et al. 2008)	Scale-dependent effects of landscape structure and composition on diurnal roost selection by forest bats	*Eptesicus fuscus, Myotis septentrionalis, Lasiurus seminolus, Lasiurus borelais, Perimyotis subflavus, Nycticeius humeralis*	X	X							X
(Reid et al. 2013)	Artificial bat roosts did not accelerate forest regeneration in abandoned pastures in southern Costa Rica	Carollia *sp. and* Glossophaga *sp.*			X				X		
(Ritzi 1999)	Utilization of the cliff swallow (*Petrochelidon pykrrhonata*) nests in west Texas by cave myotis (*Myotis velifer*)	*Myotis velifer*	X	X						X	
(Ritzi et al. 2005)	Use of bat boxes by a maternity colony of Indiana myotis (*Myotis sodalis*)	*Myotis sodalis*	X	X					X		
(Roby et al. 2011)	Characteristics of roosts used by Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) on Camp Mackall, North Carolina	*Corynorhinus rafinesquii*	X	X				X		X	
(Rueegger 2016)	Bat boxes – a review of their use and application, past, present and future	72 species across Asia, Australia, Europe, and North America	X	X	X				X		

		Type of Bat				Contained Data on Bats Roosting in					
Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Russell et al. 2009)	Road killed bats, highway design, and the communting ecology of bats	*Myotis lucifugus, Myotis sodalis*	X	X							X
(Russo and Ancillotto 2014)	Sensitivity of bats to urbanization: A review	Worldwide Review	X	X							X
(Sandel et al. 2001)	Use and selection of winter hibernacula by the eastern *Pipistrellus subflavus* in texas	*Perimyotis subflavus*	X	X				X			
(Sasse et al. 2011)	Winter roosting behavior of Rafinesque's big-eared bat in southwestern Arkansas	*Corynorhinus rafinesquii, Myotis austroriparius, Perimyotis subflavus*	X		X						
(Sasse and Saugey 2014)	Protection of water wells used as winter roosts by Rafinesque's big-eared bats	*Corynorhinus rafinesquii*		X				X			
(Sasse 2016)	Bridge roosting ecology of eastern small-footed bats in the Arkansas Ozarks	*Myotis leibii*	X		X	X					
(Scales and Wilkins 2007)	Seasonality and fidelity in roost use of the Mexican free-tailed bat, *Tadarida brasiliensis*, in an urban setting	*Tadarida brasiliensis*	X		X	X					
(Schmidt 2014)	Bat habitat and radon concentrations at roosts in abandoned uranium mines	*Corynorhinus townsendii*	X	X			X				
(Sherwin et al. 2000)	Roosting affinities of Townsend's big-eared bat (*Corynorhinus townsendii*) in northern Utah	*Corynorhinus townsendii*	X	X		X	X				
(Sherwin et al. 2003)	Managing complex systems simply: Understanding inherent variation in the use of roosts by Townsend's big-eared bat	*Corynorhinus townsendii*	X	X	X			X			
(Slider and Kurta 2011)	Surge tunnels in quarries as potential hibernacula for bats	*Perimyotis subflavus*	X		X			X			
(Slusher et al. 2015)	Altitude and sex-specific variation in roosting behavior and thermoregulation of *Myotis lucifugus* in Yellowstone National Park	*Myotis lucifugus*	X	X						X	
(Slusher et al. 2016)	Microclimates of roosting structures and the influence on thermoregulation and behavior in female *Myotis lucifugus*	*Myotis lucifugus*	X	X						X	
(Svoboda and Choate 1987)	Natural history of the Brazilian free-tailed bats in the San Luis Valley of Colorado	*Tadarida brasilensis*	X		X		X				
(Tatarian 2016a)	An effective one-way exit for Townsend's Big-eared bat (*Corynorhinus townsendii*) (BRN volume 57 pg 6)	*Corynorhinus townsendii*	X	X					X		

			Type of Bat			Contained Data on Bats Roosting in					
Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Tatarian 2016b)	Roosting by Townsend's big-eared bats (*Corynorhinus townsendii*) and Yuma myotis (*Myotis yumanensis*) in a metal pipe	*Corynorhinus townsendii, Myotis yumanensis*	X	X				X			
(Threlfall et al. 2013)	Odour cues influence predation risk at artificial bat roosts in urban bushland	Multiple species captured near Sydney, Australia							X		
(Timpone et al. 2010)	Overlap in roosting habits of Indiana bats (*Myotis sodalis*) and northern bats (*Myotis septentrionalis*).	*Myotis septentrionalis, Myotis sodalis*	X	X						X	
(Trousdale 2008)	Roosting ecology of Rafinesque's big-eared bat, *Corynorhinus rafinesquii*, in southeastern Mississippi.	*Corynorhinus rafinesquii*	X	X		X					
(Trousdale and Beckett 2002)	Bats (Mammalia: Chiroptera) recorded from mist-net and bridge surveys in southern Mississippi.	*Corynorhinus rafinesquii*	X	X		X					
(Trousdale and Beckett 2004)	Seasonal use of bridges by Rafinesque's big-eared bats, *Corynorhinus rafinesquii*, in southern Mississippi	*Corynorhinus rafinesquii*	X	X		X					
(Trousdale et al. 2008)	Short-term roost fidelity of Rafinesque's big-eared bat (*Corynorhinus rafinesquii*) varies with habitat	*Corynorhinus rafinesquii*	X	X		X					
(Turmelle et al. 2010)	Ecology of rabies virus exposure in colonies of Brazilian free tailed bats (*Tadarida brasiliensis*) at natural and man-made roosts in Texas	*Tadarida brasiliensis*	X		X	X					
(Waag et al. 2016)	Studying *Myotis lucifugus* occupancy, roost fidelity, and movements using high-frequency RFID in Yellowstone National Park	*Myotis lucifugus*	X	X						X	
(Weaver et al. 2016)	Population estimates and microclimate data for newly established overwintering Brazilian free-tailed bat colonies in central Texas	*Tadarida brasiliensis*	X		X	X					
(Whitaker et al. 2006)	Use of artificial roost structures by bats at the Indianapolis International Airport	*Myotis septentrionalis, Eptesicus fuscus, Myotis lucifugus, Lasionycteris noctivagans, Myotis sodalis*	X	X					X		
(White 2004)	Factors affecting bat house occupancy in Colorado	*Eptesicus fusucus, Myotis lucifugus*	X		X				X		

		Type of Bat				Contained Data on Bats Roosting in					
Citation	Title	Focal Species	Natives to US?	Listed	Non-Listed	Bridge	Mine	Culvert/ Pipe	Bat Boxes and Similar Roosts	Buildings / Other	Information on Bats and Roads
(Williams and Brittingham 1997)	Selection of maternity roosts by big brown bats	*Eptesicus fusucus*	X		X					X	
(Willis et al. 2009)	Thermocron iButton and iBBat temperature dataloggers emit ultrasound.	*Perimyotis subflavus, Myotis lucifugus, Myotis septentrionalis, Myotis sodalis Eptesicus fuscus*	X	X	X	X					X
(Wojtaszyn et al. 2014)	Migration of *Myotis myotis* from Poland to the Czech Republic	*Myotis myotis*		X			X		X		
(Wolters and Martin 2003)	Seasonal use of man-made structures by forest dwelling bats in west-central Mississippi	*Corynorhinus rafinesquii, Eptesicus fuscus, Myotis austroriparius, Perimyotis subflavus*	X	X		X					
(Wolters and Martin 2011)	Observations of parturition in Rafinesque's big-eared bats (*Corynorhinus refinesquii*) beneath a concrete bridge	*Corynorhinus rafinesquii*	X	X		X					
(Zara Environmental 2013)	Bat species and habitat monitoring at three bridge sites in Bell and Coryell county, Texas	*Tadarida brasiliensis*	X		X	X					
(Zara Environmental 2017)	Post construction monitoring of bat populations at three central Texas bridges	*Tadarida brasiliensis*	X		X	X					

Project Record Avaialbe at: https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4098

2.2 Results

The three-step process described above yielded a total of 169 documents. Resulting documents are listed in Table 1 and allow a searcher to rapidly locate papers on a target species or target subject. Table 1 also includes ESI's internal database numbers, thus biologists working on the project can make updates to the database during the editorial process and transmit copies of articles to TRB as part of the Project Record. As planned, the search focused on species occurring in the U.S. and yielded 146 papers. Listed species (considered rare, threatened, and endangered at the local, national, or global scales) were also well-represented with 112 papers. Focusing on types of roosts, 65 papers provided evidence of bats roosting in bridges, 14 where bats roosted in mines, 24 where bats roosted in pipes and culverts, 51 where bats roosted in buildings or other anthropogenic habitats including multiple cases of bats roosting on utility poles, and 50 cases of bats using structures (such as bat boxes) designed for their use.

2.3 Discussion

Many publications in Table 1 recorded use of artificial roosts as a secondary purpose of the writing, such as documenting bat capture from an artificial roost for inclusion in another study or as a means of obtaining distributional data. A few documents provided important insights into potential mechanisms of implementing mitigation measures via large-scale use of artificial roosts.

2.3.1 Bridges as Bat Roosts

Several efforts were made to document and describe bridges as bat habitat. The most notable review of these efforts remains Keeley and Tuttle (1999) who worked with collaborators and obtained data from 2,421 structures across 25 states. The tally included 211 bridges containing 4,250,000 bats representing 24 species. The document also included a relatively complete review of previously available literature. The authors concluded bats were most likely to use concrete cracks (typically expansion joints) with a "roof," width of 0.5 to 1.25 inches (1.3 to 3.2 cm), a depth of at least 12 inches (30.5 cm), and positioned at least 10 feet (3 m) above the ground. Trends illuminated by the study indicated bridges lacking shade, in the southern half of the U.S., constructed primarily of concrete, and not located over busy roadways were more likely to be used by bats. Less than 1% of bridges examined in the study met these criteria.

The general findings of Keeley and Tuttle (1999) are supported by several subsequent studies that determined bridges most likely to be used by bats are of concrete construction and contain crevices in which bats roost (Davis and Cockrum 1963, Hirshfeld et al. 1977, Fraze and Wilkins 1990, Adam and Hayes 2000, Lance et al. 2001, McDonnell 2001, Trousdale and Beckett 2002, Diamond and Diamond 2003, Feldhamer et al. 2003, Keeley and Keeley 2004, Ferrara and Leberg 2005a; b, Celuch and Sevcik 2008, Trousdale 2008, BCI 2011, Amorim et al. 2013, Martinez et al. 2015, Sasse 2016). Several authors also noted the potential value of protected open spaces found under bridge decks and between supporting structures such as I-beams constructed of concrete or steel. Open spaces are used by bats during both the day and night and may be used by species that typically roost in caves and trees (Keeley and Tuttle 1999, Adam and Hayes 2000, McDonnell 2001, Johnson et al. 2002, Kiser et al. 2002, Keeley and Keeley 2004, Trousdale and Beckett 2004, Bennett 2005, Bennett et al. 2008, Trousdale 2008, Trousdale et al. 2008, Willis et al. 2009, Amorim et al. 2013, Zara Environmental 2013, Cervone and Yeager 2016). Open roosts are potentially significant as some species using them face substantial conservation issues. Installation of roosting structures on concrete bridges that otherwise lack high suitability roosting sites remains among the most cost-effective means of supplementing bat habitat (Keeley and Tuttle 1999, Arnett and Hayes 2000, BCI 2011). Wooden bridges (especially those with suitable crevices) are important in desert Southwest (Davis and Cockrum 1963, Keeley and Tuttle 1999, Geluso and Mink 2009), perhaps due to limited roosting opportunities and perhaps due to higher ambient temperatures in the region.

Bektas et al. (2018) used logistic regression to create a model that separated 124 bridges in Iowa that provided evidence of use by bats from 393 that appeared unoccupied. The model revealed increased potential for bat use when bridges are continuous (i.e., all one structure) and made of prestressed concrete or a mix of prestressed concrete and steel, are tall, provide deep spaces for bats, are in areas where multiple bats species are expected, and a relatively large amount of wetlands exists within 0.1 mile (0.16 km) of the structure.

2.3.2 Effectiveness of Stand-alone Roosts (Boxes)

Although bat boxes (and similar structures) enjoy great popularity with the public, few studies successfully completed and reported long-term management effectiveness for populations of bats. Perhaps the best-known success is described in studies completed at the Indianapolis International Airport (IND) where colonies of Indiana (*Myotis sodalis*) and northern long-eared (*Myotis septentrionalis*) bats made regular use of bat boxes for many years (Ritzi et al. 2005, Sparks et al. 2009, Hoeh and O'Keefe 2015, Hoeh et al. 2018). The boxes at IND were in place for nearly a decade prior to receiving regular use from the Indiana bat, and this change coincided with the loss of an important roost (Sparks et al. 2009). Similarly, other authors also noted artificial roosts are most likely selected by bats lacking other roosting opportunities (Neilson and Fenton 1994, Brittingham and Williams 2000, White 2004, Mering and Chambers 2014, Adams et al. 2015). As is the case for bridges and roosts in trees, boxes are most successful when they are exposed to direct sun (Kerth et al. 2000, Long 2003, White 2004, Ciechanowski 2005, Whitaker et al. 2006, Goldingay and Stevens 2009, Adams et al. 2015). In fact, cooperating with utilities to place roosts on existing utility poles may provide a ubiquitous and cost-effective means of installing stand-alone artificial roosts (Farrell Sparks et al. 2004).

2.3.3 Incorporating Cues from Building Roosts

Several recent efforts examined roost selection of bats within and among buildings (Barclay et al. 1980, O'Keefe and LaVoie 2011, Berkova et al. 2014, Fagan et al. 2018). These studies provide a suite of variables including level of disturbance, advanced microclimate measurements, and landscape placement that will be considered for the comparative performance analysis. An important predictor variable in several of these studies included the building's age. The value of older structures for bats warrants consideration as DOTs also face requirements to protect and manage historic structures (Fagan et al. 2018).

2.3.4 Incorporating Other Forms of Mitigation

The current study focuses on use of artificial roosts (including highway infrastructure) as mitigation for bat habitat. However, the federal DOT recently entered an agreement with the U.S. Fish and Wildlife Service (USFWS) to address impacts of highways on Indiana and northern long-eared bats (USFWS 2016a). The agreement requires bridges are checked for bat presence or sign prior to scheduled repairs or demolition. At present, the agreement does not recognize the value of bridges or other artificial roosts as a mitigation tool. Notably, in cases where artificial roosts are deemed an important part of a successful mitigation effort (Ritzi et al. 2005, Sparks et al. 2009, Gumbert et al. 2013, Adams et al. 2015, Hoeh and O'Keefe 2015, Dobony and Johnson 2018), they are considered ancillary to a larger mitigation program.

3.0 Practitioner Survey

3.1 Introduction

The survey's purpose was three-fold. It's primary objective included obtaining information on how State DOTs address issues related to bats using highway infrastructure (especially bridges) and what steps were taken to provide mitigation for bat habitat impacted by highway developments. The questionnaire's second goal included identifying baseline information concerning the extent to which bats use artificial roosts associated with highways (especially bridges). The third goal focused on identifying individuals and organizations that can (and would) provide detailed information about how bats use these artificial roosts.

3.2 Methods

3.2.1 Survey Development and Delivery

A questionnaire was developed in coordination with the research panel and was distributed to 90 recipients via e-mail on 20 April 2018 (Appendix A). The survey was developed using a web-based, interactive platform (Qualtrics®) that allows users to complete the survey on devices ranging from smart phones to desktop computers. As such, an individual's response to a screening question determines whether he or she sees follow-up questions. For example the survey began with questions aimed at understanding whether and how the number of bats present in a bridge or a free-standing artificial roost is determined. Individuals who responded in the affirmative were then asked follow-up questions regarding the type of data collected.

Following the initial e-mail, the research team received eight delivery error messages. Five were resolved by sending a second e-mail. In two other cases, e-mails were re-sent to a general help line at the agency. The research team also tried social media (LinkedIn©) to locate a person that had changed jobs.

3.2.2 Recipients

The questionnaire was distributed to 90 people. The recipients included at least one contact from each of the 50 states. The list comprises DOT employees representing 46 states (52 contacts), and 37 contacts representing a cross-section of state natural resource and wildlife agencies (17 contacts), academia (14 contacts), USFWS (5 contacts), and consultants (2).

At least five of the initial recipients forwarded the survey to colleagues. In particular, multiple responses from California were received.

3.2.3 Data Processing

Results were downloaded on 27 August 2018, and a copy of the results was preserved for the Project Record. Submissions were then filtered to remove incomplete surveys, test runs completed by the research team prior to releasing the survey, and (by matching IP addresses) to eliminate duplicate responses.

3.3 Questionnaire Results

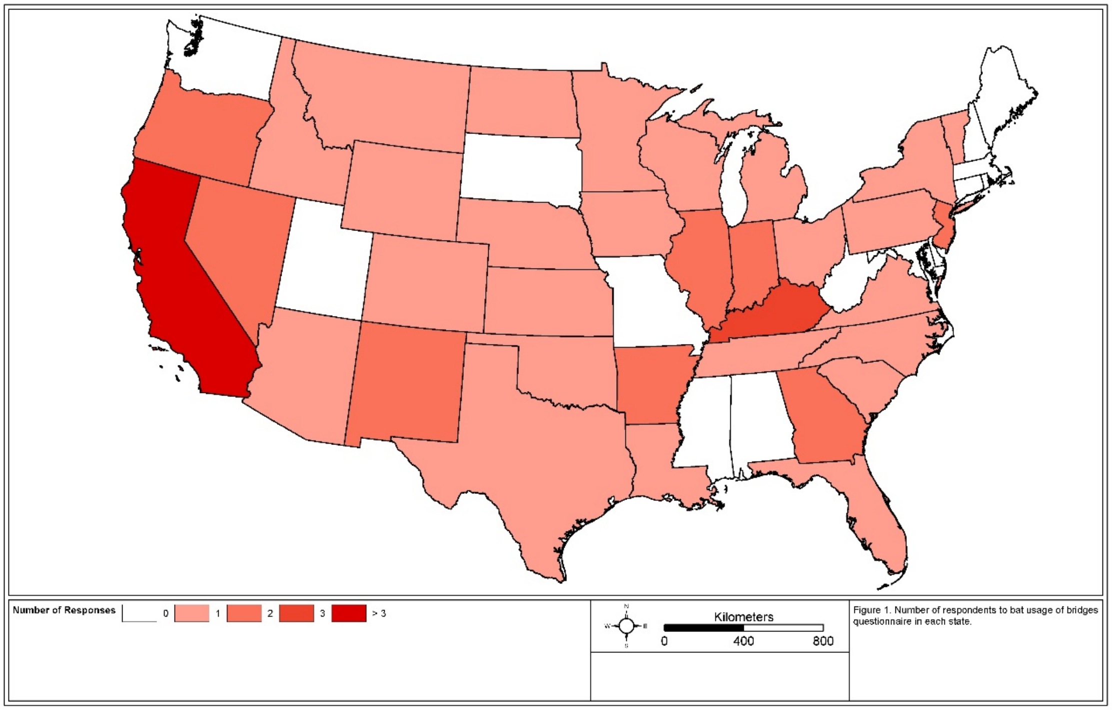
Fifty-six completed and six partially completed responses were received. Because none of the partially completed responses were duplicates, they were included in the analysis. Respondents from California represented 19 of 62 responses, but nationwide results were only skewed by the uneven data set for questions related to regulations or definitions of mitigation success.

Each question, a summary of all answers received, and additional responses to questions provided by some respondents are provided in Appendix A. A summary of responses from completed surveys is provided below.

Sixty-two participants responded to the questionnaire, representing 34 states (Figure 1). Thirty-nine participants were biologists employed by a transportation agency, 11 participants were employed by natural resource and wildlife agencies, 6 were transportation professionals, 4 were academic biologists, and 2 were consultants. Responses from participants include:

- Forty-nine of 62 respondents were aware of bat colonies in bridges (88%) or culverts (12%) within their respective areas, while 12 were unaware
- Thirty-one participants indicated surveys of roadways and bridges were completed in their areas within the past 10 years, while 30 participants indicated a lack of roadway and bridge surveys within the past 10 years

Figure 1. Number of respondents to bat usage of bridges questionnaire in each state.



- Twenty-two participants were aware of bat colonies in free-standing artificial roosts in their respective areas
- The primary reason for pursuing bat mitigation was compliance with the federal Endangered Species Act (ESA)
- Preservation of bat colonies in existing bridges was reported as the most successful method for providing bat habitat, and engineering bridges for bat use was not regularly attempted
- The question of how successful mitigation is determined elicited a variety of responses, with the greatest number of participants (24) indicating use by any number or bat species was enough to satisfy the mark of success
- Thirty-four of 41 participants did not target particular species in creating bat habitat

3.4 Follow-up Interviews

Follow-up interviews were conducted from 12 to 20 June 2018. Calls began with a series of pre-determined questions identified in the draft questionnaire. Questions included requests for information regarding the geographic locations where bats were found, how many were spread among bridges and culverts, the type of use ranging from sporadic nocturnal use by individual bats to regular use by maternity colonies, to information about mitigation efforts. However, each interview was also allowed the freedom to organically evolve.

3.5 Analysis

Several trends were noted by the research team during the interviews and upon reviewing the responses to the initial survey. First, trends observed by Keeley and Tuttle (1999) remain largely true. Bridges that contain bats tend to "provide concrete crevices that were sealed at the top, at least 6 to 12 inches (15.2 to 30.5 cm) deep, 0.5 to 1.25 inches (1.3 to 3.8 cm) wide, and 10 feet (3.0 m) or more above ground, typically not located over busy roadways." However these authors also observed bridges in the northern half the U.S. are rarely used by bats – the documentation of large bat colonies in a bridge along the Minnesota/Wisconsin border (Kaarakka 2017) indicates revisiting this observation is warranted. Perhaps an important contributor to the apparent discrepancy is the absence of the species most commonly observed by Keeley and Tuttle (i.e., the Brazilian free-tailed bat, *Tadarida brasiliensis*, which includes the subspecies Mexican free-tailed bat, *T. b. mexicana*) across the northern half of the country (Karsk et al. 2018).

Second, with the exception of Texas, culverts associated with highway infrastructure are rarely used. Box culverts are most frequently used; however, unusual instances such as multiple segments of culvert linked together to form cave-like environments may attract bats in other states.

Several observations suggest culvert pipes that mimic cave-like conditions are a potentially cost-effective means of providing bat habitat. The western-most record of a gray bat colony is in a storm drain in Kansas (Sparks and Choate 2000) constructed of linked segments of 10-foot (3.04 m) diameter culvert (D.W. Sparks, Unpublished). Similarly two surge tunnels (made of culvert pipes) at an abandoned quarry along the shore of Lake Huron in Michigan provide hibernacula for big brown, little brown, and tricolored bats (Slider and Kurta 2011). All but one of the bats were found in a tunnel measuring 492 feet (150 m) long, sealed along the sides, and primarily buried in gravel. Segments of large diameter pipe (like those used for culverts) are routinely used to stabilize mine entrances thus excluding unauthorized people, but allowing bat passage (Perry et al. 2010). Finally, bats in southwestern Arkansas regularly hibernate in stone-lined and hand-dug wells during winter months (Sasse et al. 2011).

Third, some confusion remains among biologists regarding different types of bridge design and confusion among engineers and maintenance workers about how to recognize good bat habitat. Both groups need an exchange of information leading to development of a more enlightened ability to predict the likelihood of any given bridge being used by bats.

Fourth, DOTs and their sister agencies responsible for natural resources and wildlife (usually Departments of Natural Resources) are increasingly forming partnerships to address issues related to bats and highways. Participants of in-person interviews identified such cooperation as an important component of successful mitigation efforts or as a component likely useful for improving less-successful projects. Disparities in assessing successful mitigation studies, limited information on mitigation options that provide quality bat habitat, the need to protect bat roosts as confidential data, and the sheer number of bridges and culverts that could contain bats are among the challenges these developing partnerships face. Several states address the latter challenge by encouraging data collection during routine structural inspections of bridges.

4.0 Comparison of Bridge Designs

4.1 Introduction

The purpose of bridge design comparison includes analyzing data collected during previous tasks to develop an understanding of the types of bridges and culverts most likely to serve as roosts for bats throughout North America, and to extrapolate from that data set opportunities to retrofit otherwise unsuitable bridges and culverts as a means of providing habitat for bats. As noted in Section 2.3.1, biologists have long known that some bats use bridges as roosts, providing both an opportunity for conservation and opportunities for human/wildlife conflicts.

Bridges, culverts, and associated transportation infrastructure could provide discrete locations and serve as a centroid for protection and management of bats roosting there. Unlike trees used by many bats as summer roosts, bridges and culverts may be suitable for decades at a time (Lewis 1995). Bridges are typically used to span streams, roads, canyons, and other linear landscape elements that in-turn are used for navigation by bats. Similarly, culverts are typically used to convey water under a roadway. The unique placement of bridges and culverts across linear landscape elements provides biologists a relatively clear-cut means to delineate (via Geographic Information System [GIS]) likely foraging and commuting habitats associated with a colony of bats to target conservation efforts.

Bats in bridges can also lead to conflicts between humans and wildlife. Urine and feces can retain moisture and potentially damage bridge components, especially metal (Keeley and Tuttle 1999). The public strongly associates bats with a variety of diseases, including rabies (Shankar et al. 2004) and histoplasmosis (Benedict and Mody 2016). While the risk of these diseases to humans from free-ranging bats is minimal, it could be a concern if maintenance workers enter bat roosts without proper safety precautions. Similarly, vehicle strikes are an under-appreciated source of bat mortality (Lesinski 2007, Russell et al. 2009, Lesiński et al. 2010, Bennett and Zurcher 2013). Conceivably, bats roosting in transportation infrastructure may face an increased risk of being struck. Bat protection must be balanced with bridge maintenance, repair, and replacement, such that a bridge continues to serve its primary role as transportation infrastructure.

Studies enabling both engineers and biologists to identify or predict bridges most likely to support bats potentially benefit both bats and people. Several efforts were made to document and describe bridge use by bats. Keeley and Tuttle (1999) worked with collaborators and obtained data from 2,421 structures across 25 states, including 211 bridges containing 4,250,000 bats representing 24 species. The authors concluded that bats were most likely to use cracks (typically expansion joints) in concrete bridges with a "roof," a width of 0.5 to 1.25 inches (1.27 to 3.18 cm), a depth of at least 12 inches (30.5 cm), and positioned at least 10 feet (3.05 m) above the ground. Bridges with these features were more likely selected for bat use if they were in the southern half of the U.S., were exposed to direct sunlight, and did not span busy roads. Subsequent studies provided support for the contention that bats are most likely to roost in concrete bridges with crevices (Adam and Hayes 2000, Lance et al. 2001, McDonnell 2001, Trousdale and Beckett 2002, Diamond and Diamond 2003, Feldhamer et al. 2003, Keeley and Keeley 2004, Ferrara and Leberg 2005a; b, Celuch and Sevcik 2008, Trousdale 2008, BCI 2011, Amorim et al. 2013, Martinez et al. 2015, Sasse 2016), although some authors identified the value of protected open space beneath bridges that mimic caves and hollow trees (Keeley and Tuttle 1999, Adam and Hayes 2000, McDonnell 2001, Johnson et al. 2002, Kiser et al. 2002, Keeley and Keeley 2004, Trousdale and Beckett 2004, Bennett 2005, Bennett et al. 2008, Trousdale 2008, Trousdale et al. 2008, Willis et al. 2009, Amorim et al. 2013, Zara Environmental 2013, Cervone and Yeager 2016). Recently, Bektas et al. (2018) completed the first large-scale, statistically-robust analysis, of bats roosting under bridges across a large area (Iowa). Using logistic regression, the paper revealed an increase in bat use when bridges are continuous (i.e., all one structure), made of prestressed concrete or a mix of prestressed concrete and steel, tall, provide deep spaces for bats, within 0.1 mile (0.16 km) of wetlands, and are in regions where multiple bat species occur.

4.2 Methods

Two separate analyses were completed on two different data sets. The first comprises a meta-analysis of data obtained through a variety of publications and technical reports. The strength of this analysis includes combining data obtained by multiple authors using multiple techniques and from multiple localities. However, the analysis can only be completed using limited variables shared amongst these studies. The second comprises independent analysis of a data set provided by the Minnesota Department of Transportation. The data set contains observations of bats in bridges and culverts collected when structures were inspected for structural issues. As such, the data set was collected by maintenance workers and engineers as opposed to trained bat biologists. A key component, information about the types of areas (cracks, crevices, protected open space, or cave-like recesses) used by roosting bats, is missing from both data sets.

4.2.1 Identification and Extraction of Roosting Data

4.2.1.1 Nationwide Data Set (Meta-Analysis)

Data on use of highway structures by bats were extracted from the literature review completed and detailed in Section 2.0 above as well as unpublished data (results of the questionnaire and follow-up interviews) provided to the authors (Section 3.0). Documents were reviewed for information associated with bat use and types of highway structures used. Sources detailing structures used were divided into two subcategories: those that randomly or systematically sampled bridges to determine roosting habits of bats in bridges (termed random studies), and those targeting bridges with known bat use (non-random).

From these documents, study location, bat presence or absence, bridge design, and bridge construction materials were determined. Structure designs were grouped into 13 categories: I-beam, T-beam, box beam, channel beam, cast-in-place, slab, girder, truss, culvert, box culvert, pipe culvert, several culverts, or parapet. Construction materials were grouped as concrete, steel, timbers, or stone. Where bats were present, the number of bats by species, and whether the structure was used as a day or night roost were determined. Although not always explicitly stated, most data identified bat use of structures during summer.

4.2.1.2 Data Provided by the Minnesota DOT

A second data set was provided by the Minnesota DOT. During structural inspections of bridges, Minnesota DOT engineers look for and note the presence of bats. Limited follow-up analysis by Mr. C. Smith, a biologist with Minnesota DOT, noted that in most cases engineer's reports were accurate and never provided false positives, but bat signs were occasionally overlooked. This data set provides no information on bats other than presence, but does provide detailed information associated with the bridge. Data on the presence/absence of roosting bats were extracted from the larger data set. Data collected for each inspected bridge included descriptive information regarding bridge location, feature crossed, design type, owner, dimensions, age, deck type, and number of lanes.

4.2.2 Data Analysis

Descriptive statistics were compiled for both the random and nonrandom study data sets. Additional analyses were completed on only the random studies data set where known bat use (or non-use) did not influence the study choices.

4.2.2.1 Nationwide Data Set (Meta-Analysis)

Data from the random studies were evaluated using presence/absence modeling (Brotons et al. 2004). Data were divided into two groups – for training and testing. For this analysis, a binomial logistic regression was used to examine the presence/absence of bats in the training data set in relation to the following variables: location, structure type, structure design, and construction material (Table 2).

Table 2. Variables used to fit logistic regression

Variable	Description
State	12 categories: OR, GA, IN, IL, MT, SC, LA, NM, NC, MS, UT, FL
Structure Type	2 categories: bridge, culvert
Structure Design	13 categories: I-beam, T-beam, box beam, channel beam, cast-in-place, slab, girder, truss, culvert, box culvert, pipe culvert, several culverts, parapet
Construction Material	4 categories: concrete, steel, timbers, stone

Fit of the training model was evaluated using a stepwise method whereby variables were removed from the model and only variables that improved the fit of the model were retained. The final training model was selected based on Akaike Information Criteria (AIC) values.

Predictive power of the training model was evaluated by using it to predict occupancy in the testing data. The effectiveness of the model was evaluated by generating an Area Under Curve (AUC) based on Receiver Operator Characteristic (ROC) curves whereby, an AUC of 0.5 is the same as random because background and occurrence points are assigned to each group randomly. Models that better predict bridge occupancy generate AUCs closer to 1.0 (data were correctly assigned occupancy): AUC scores between 0.7 and 0.8 are considered fair to good, and scores above 0.9 are considered excellent (Swets 1988). All statistical analyses were performed with R version 3.3.1.

4.2.2.2 Data Provided by the Minnesota DOT

4.2.2.2.1 Modeling

Using the same techniques outlined above for the nationwide data set, a binary logistic regression was run to separate bridges containing bats from those that did not. However, the separation between bridges with bats and without bats was complete, thus efforts to examine individual components were completed using pairwise comparison of variables.

4.2.2.2.2 Pairwise Comparison of Variables

Aspects of bridges that played a role in bat presence/absence were evaluated via a series of statistical tests on features that were expected (based on logistic regression models) to be applicable to bridges on a larger spatial scale. Tests allowed a direct comparison between bridges with bats and bridges without bats. Chi-square tests were performed on categorical variables and Welch's two sample t-tests were performed on continuous variables. Benjamini-Hochberg corrections were used on t-tests to account for multiple testing. Bridge design type, feature crossed, and deck type were included as categorical variables that influence bat presence/absence (Table 3). Continuous variables included bridge main span length (ft), structure length (ft), and width (ft). Each continuous variable was log transformed to a normal distribution.

Table 3. Categorical variables used to describe Minnesota data.

Variable	Description
Feature Crossed	10 categories: Waterway, Railroad, Highway (w/ or w/out ped), Pedestrian - bicycle, Highway - railroad, Highway-waterway-railroad, Railroad - waterway, Relief for waterway, Highway - waterway, Other
Deck Type	11 categories: Concrete Cast-in-Place, Wood or Timber, Concrete Precast Panels, Steel Plate, Open Grating, Closed Grating, Corrugated Steel, Aluminum, Unknown (NBI), Other, Not Applicable
Design Type	88 categories from a combination of the following construction materials and design types: Construction material: Prestress or Precast, Prestress Continuous, Concrete Continuous, Post-Tensioned, Concrete, Steel, Steel Continuous, Aluminum, Wrought or Cast Iron, Timber, Masonry, Other Beam Span, Slab Span, Quad Tee, Double Tee, Pipe Arch, Low Truss, Thru Girder, Box Girder, Rigid Frame, Deck Girder, Arch, Inverted Tee Beam, Channel Span, Bulb Tee, High Truss, Other, Long Span, Tied Arch, Slab Span (V), Deck Truss, Continuous Slab Span (V), Suspension, Continuous High Truss, Moveable, Pipe Culvert (Round), Box Culvert

4.3 Results

4.3.1 Nationwide Data Set (Meta-Analysis)

4.3.1.1 Descriptive Statistics

Eighty-nine papers mentioned bats using bridges or culverts for roosts; 31 contained information on structure design and construction materials, and represented 3,964 bridges and culverts (Table 4). Fourteen studies sampled bridges in either a random or systematic way and included data on 3,913 bridges and culverts for presence or absence of bats. The model was built using data from the smaller, more systematic group of studies containing 3,913 bridges.

4.3.1.1.1 Type of Bridge

I-beam bridges were most abundant in the data set although more T-beam bridges contained bats (Figure 2). Channel beam bridges occurred only in North Carolina, were a small part of the sample, but represented the highest occupation (69%, Figure 3). Collectively, 19% of bridges and 5% of culverts showed signs of bat use (Figure 2). Of 653 slab bridges in the data set, 11 were used by bats – likely because no spaces for roosting bats exist on this bridge type. Collectively, eighty-six percent of occupied bridges were I-beam, T-beam, channel beam, or box-beam designs (Figure 4)

4.3.1.1.2 Type of Structure Material

The data set was dominated by concrete structures (Figure 5), with eighty-three percent of occupied bridges being concrete. The single stone culvert sampled contained bats, but was studied because it was a known roost.

Table 4. Literature sources that were used in the meta-analysis

Citation	Title	State	Number of Highway Structures	Used in Logistic Regression
Adam and Hayes (2000)	Use of bridges as night roosts by bats in the Oregon coast range	Oregon	50	Yes
Allen et al. (2011)	Variation in physiological stress between bridge- and cave-roosting Brazilian free-tailed bats	Texas	3	No
Bennet et al. (2008)	Use and selection of bridges as day roosts by Rafinesque's big-eared bats	South Carolina	1129	Yes
Cervone and Yeager (2016)	Bats under an Indiana bridge	Indiana	1	No
Diamond and Diamond (2003)	Bat use of box style bridges on highway systems in Beaver, Iron, and Washington counties of southwestern Utah	Utah	105	Yes
Feldhamer et al. (2003)	Use of bridges as day roosts by bats in southern Illinois	Illinois	240	Yes
Ferrara and Leberg (2005a)	Characteristics of positions selected by day-roosting bats under bridges in Louisiana	Louisiana	63	Yes
Fraze and Wilkins (1990)	Patterns of use of man-made roosts by *Tadarida brasiliensis mexicana* in Texas	Texas	2	No
Geluso and Mink (2009)	Use of bridges by bats (Mammalia: Chiroptera) in Rio Grande Valley, New Mexico	New Mexico	17	Yes
Geluso et al. (2018)	Night-roosting behaviors for the northern long-eared Myotis (*Myotis septentrionalis*) under a bridge revealed by time-lapse photography	Nebraska	1	No
Goehring (1954)	*Pipistrellus subflavus obscurus, Myotis keenii*, and *Eptesicus fuscus fuscus* hibernating in a storm sewer in central Minnesota	Minnesota	1	No
Gore and Studenroth (2005)	Status and management of bats roosting in bridges in Florida	Florida	299	Yes
Hendricks et al. (2005b)	Bat use of highway bridges in south-central Montana	Montana	130	Yes
Hirshfield et al. (1977)	Night roosting behavior in four species of desert bats	Nevada	1	No
Jackson et al. (1982)	Cave myotis roosting in barn swallow nests	Texas	2	No
Johnson et al. (2002)	Gray bat night-roosting under bridges	Georgia	37	Yes

Citation	Title	State	Number of Highway Structures	Used in Logistic Regression
Johnson et al. (2012)	Social networks of Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) in bottomland hardwood forests	Kentucky	1	No
Karsk et al. (2018)	Bat roosts in bridges: Assessing Illinois bridges for bat use	Illinois	175	Yes
Keeley and Keeley (2004)	The Mating system of *Tadarida brasiliensis* (Chiroptera: Molossidae) in a large highway bridge colony	Texas	1	No
Kiser et al. (2002)	Use of concrete bridges as night roosts	Indiana	7	Yes
Lance et al. (2001)	Day roost selection by Rafinesque's big-eared bats (*Corynorhinus rafinesquii*) in Louisiana forests	Louisiana	81	Yes
McDonnell (2001)	Use of bridges as day roosts by bats in the North Carolina Coastal Plain	North Carolina	990	Yes
Perlmeter (1996)	Bats and bridges: Patterns of night roost activity in the Willamette National Forest	Oregon	5	No
Sandel et al. (2001)	Use and selection of winter hibernacula by the eastern *Pipistrellus subflavus* in texas	Texas	4	No
Sasse (2016)	Bridge roosting ecology of eastern small-footed bats in the Arkansas Ozarks	Arkansas	0	No
Slider and Kurta (2011)	Surge tunnels in quarries as potential hibernacula for bats	Michigan	2	No
Tatarian (2016b)	Roosting by Townsend's big-eared bats (*Corynorhinus townsendii*) and Yuma myotis (*Myotis yumanensis*) in a metal pipe	California	1	No
Trousdale (2008)	Roosting ecology of Rafinesque's big-eared bat, *Corynorhinus rafinesquii*, in southeastern Mississippi.	Mississippi	90	Yes
Wolters and Martin (2003)	Seasonal use of man-made structures by forest dwelling bats in west-central Mississippi	Mississippi	1	No
Wolters and Martin (2011)	Observations of parturition in Rafinesque's big-eared bats (*Corynorhinus rafinesquiii*) beneath a concrete bridge	Mississippi	1	No

[1] Call numbers are included to allow rapid response to future requests for information and reference to materials that will be submitted as part of the project record.

Figure 2. Number of highway structures with bat presence and absence based structure.

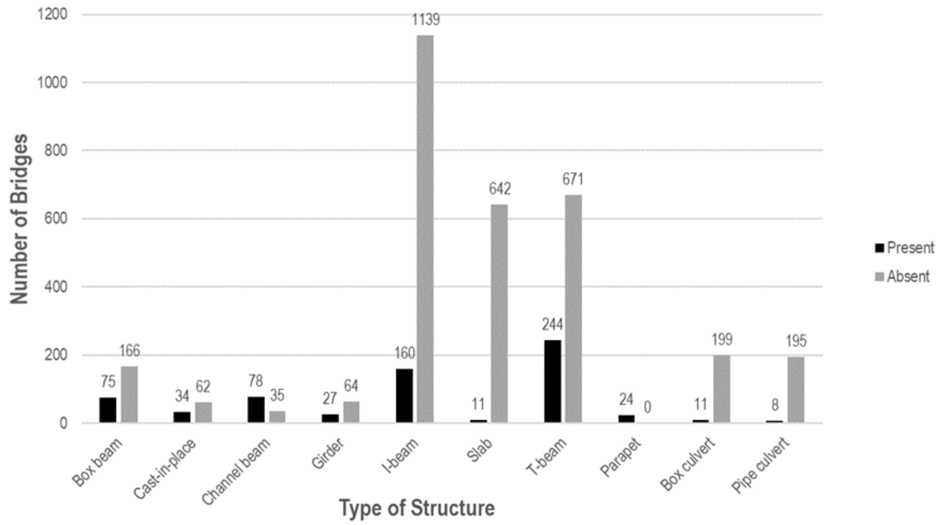


Figure 3. Occupancy rates of different structure types.

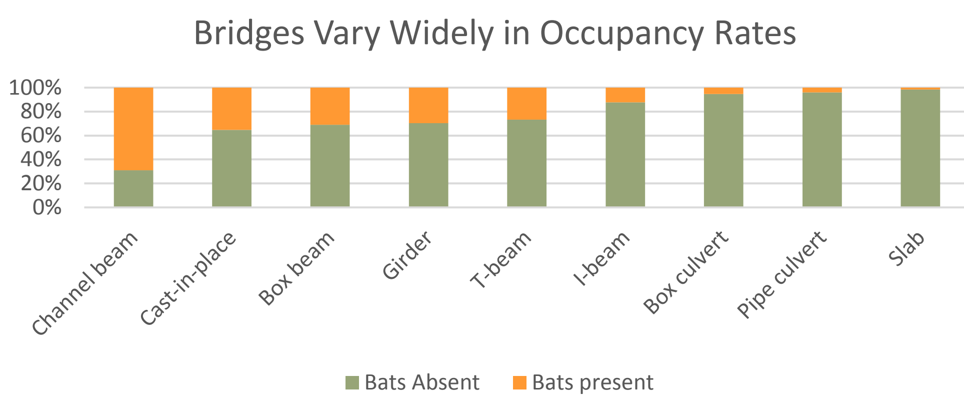


Figure 4. 86% of occupied bridges belong to four designs.

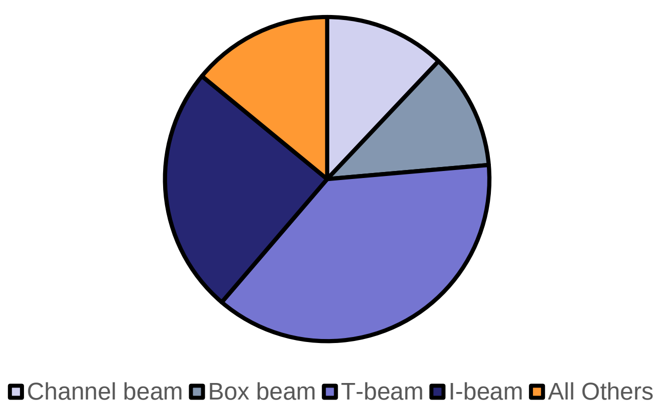
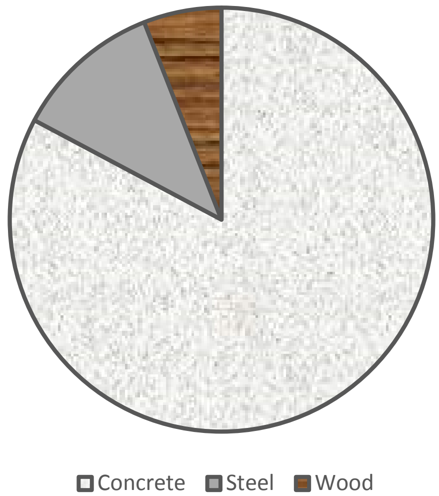


Figure 5. 83% of Occupied Bridges are Constructed of Concrete.



4.3.1.2 Modeling

The logistic regression model with the best fit (Table 5) included location (χ^2=635, df=11, $p < 0.001$), bridge design (χ^2=389, df=10, $p < 0.001$), and bridge material (χ^2=29, df=2, $p < 0.001$) as variables that best described the fit. The AUC value for the testing subset was 0.88, indicating the model has good to excellent predictive power.

Bridges in New Mexico, Oregon, Utah, Montana, Louisiana, and Illinois were positively associated with bats, whereas bridges in South Carolina were unlikely to be used. Notably, data from South Carolina focused on the presence of a single, rare species: Rafinesque's big-eared bat (Bennett et al. 2008). Structure designs associated with bat presence (in order of use) include channel beam, I-beam, and T-beam bridges. Conversely, slab bridges and box culverts were likely unoccupied. Steel bridges were an excellent predictor of bat absence – no other construction material was an independent predictor of presence or absence.

Table 5. Summary of logistic regression.

Independent Variable	β[1]	OR	95% Confidence Interval
State			
Florida	-	-	(-, -)
Georgia	-0.3	0.74	(0.11, 2.83)
Illinois	1.8	6.05***	(3.07, 12.37)
Indiana	17.7	>1000	(0, NA)
Louisiana	2.9	18.4***	(8.3, 42.63)
Mississippi	17.0	>1000	(0.01, NA)
Montana	3.4	30.9***	(15.36, 65.17)
North Carolina	0.7	1.94	(0.99, 3.92)

Independent Variable	β[1]	OR	95% Confidence Interval
New Mexico	6.2	472***	(87.99, 3824.55)
Oregon	4.9	129***	(44.99, 388.17)
South Carolina	-1.2	0.3***	(0.14, 0.61)
Utah	4.2	66.4***	(23.67, 197.85)
Structure Design			
Box beam	-	-	(-, -)
Box culvert	-1.7	0.18*	(0.03, 0.7)
Cast-in-place	0.4	1.44	(0.53, 3.91)
Channel beam	4.1	62.2***	(24.3, 170.4)
Girder	-0.2	0.8	(0.23, 2.89)
I-beam	1.8	6.17***	(2.8, 14.58)
Pipe culvert	-0.1	0.93	(0.22, 3.26)
Slab	-1.5	0.23**	(0.08, 0.65)
T-beam	2.1	8.46***	(3.78, 20.29)
Truss	-27.9	0	(NA, NA)
Unknown	-13.4	0	(0, 0)
Construction material			
Concrete	-	-	(-, -)
Steel	-1.4	0.24***	(0.14, 0.4)
Timbers	-0.8	0.46	(0.2, 0.99)

[1] β represents the regression coeficcient, a measure of the strength of the relationship, OR is the odds Ratio, and a dash (-) is used to symbolize a lack of data.

Significant odds ratio (OR) values greater than 1 have higher odds of predicting bat use and significant OR values less than 1 are more likely to predict bat absence. Variables contributing significantly to the model are identified with "*" (* = p ≤ 0.05; ** = p ≤ 0.01; *** = p ≤ 0.001). NA = values that had too small of sample size to be estimated confidently.

4.3.2 Minnesota DOT Data

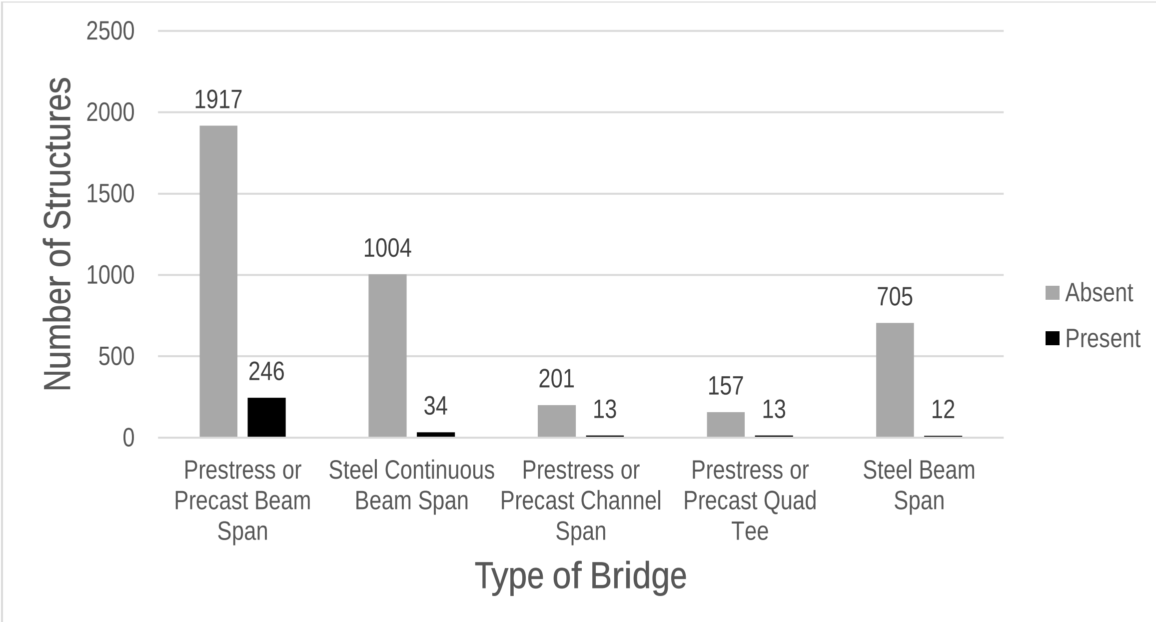
4.3.2.1 Descriptive Statistics

Minnesota DOT performed inspections for bats on 14,406 of 21,086 highway structures in the state. Of bridges surveyed, 2.4% (355 structures) had evidence of roosting bats.

4.3.2.1.1 Type of Structure

In Minnesota, prestress or precast beam span designs accounted for the highest frequency (69%) of roosting bats (Figure 6), in highway structures containing bats. Furthermore, Figure 6 shows that in the top five most frequently used highway structures, beam span comprises the primary structural factor influencing likelihood of use and accounts for 82% of highway structures with bat presence.

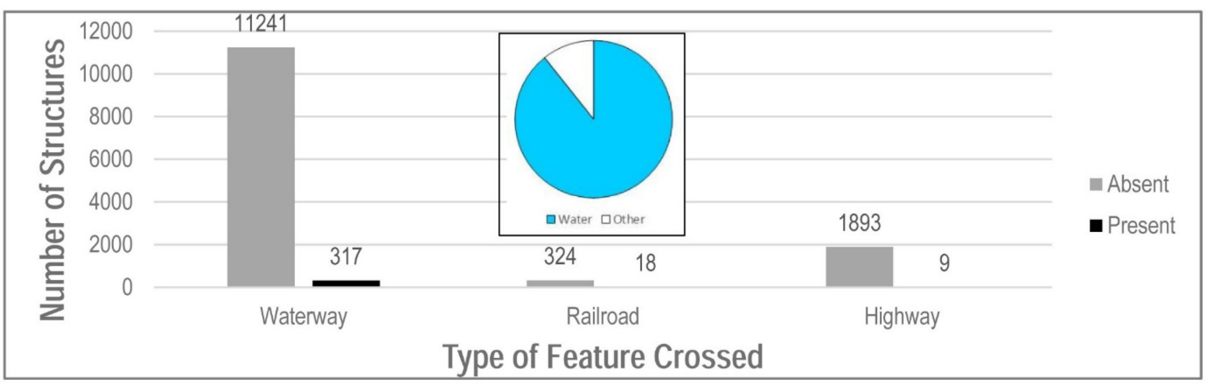
Figure 6. Number of highway structures with bat presence and absence based structure design.



4.3.2.1.2 Types of Features Crossed

Bats were found in bridges over waterways, railroads and highways (Figure 7). Waterways (Figure 7, inset) accounted for 89% of highway structures with bats presence. Although this number seems high, 81% of highway structures in Minnesota span a waterway.

Figure 7. Bats occur in bridges over a variety of structures (bar chart), but 89% of occupied bridges are over water (inset pie chart).



4.3.2.1.3 Type of Deck

Bridges with concrete cast-in-place decks were most frequently used by bats (Figure 6), and account for 93% of highway structures that contained bats, but represent only 36% of highway structures in the state. Eighteen bridges decked with precast panels or timber were also occupied. Bats were absent from 7629 bridges with other decking material.

Figure 8. 93 % of Occupied Bridges in Minnesota Are Over Water. Some Bridges Cross Multiple Features.

4.3.2.2 Comparative Analysis

For all variables examined, significant differences were noted between bridges with bats and bridges without bats (Table 6). Bats were present in 219 prestress or precast beam span bridges with a concrete, cast-in-place deck and that crossed a waterway The combination of attributes accounted for 62% of bridges where bats were found, but represented only 7.5% of the total sample.

Table 6. Summary of pairwise comparisons between bridges with and bridges without bats.

Variable Compared	Test Statistic and Results	Key Factor
Type of Design	$X^2 = 1155$, df = 87, $p < 0.001$	69% of bridges containing bats were prestressed or precast span bridges
Feature Crossed	$X^2 = 92$, df = 10, $p < 0.001$	89% of bridges containing bats crossed waterways
Type of Deck	$X^2 = 530$, df = 10, $p < 0.001$)	93% of bridges containing bats had concrete cast-in-place decks
Structure Length	t = -28, df = 388.08, $p < 0.001$	Average length with bats = 165 ft, Average length without bats = 46 ft
Length of the Main Span	t = -37, df = 408.56, $p < 0.001$.	Average length with bats = 72 ft, Average length without bats = 24 ft
Width of the bridge	t = -4.2, df = 456.15, $p < 0.001$	Average width with bats = 37 ft, Average width without bats = 35 ft

4.4 Discussion

4.4.1 Nationwide (Literature-Based) Data Set

Based on the nationwide meta-analysis, the state where the study was completed serves as the most important variable to predict bridge use by bats. The importance of this variable is likely tied to a lack of other important variables in the data sets such as species of bats available to use each bridge, types of bridges present, microclimates within and under the bridges, and habitat near each bridge, all of which vary among states.

Perhaps key to this issue is the presence or absence of the Brazilian free-tailed bat in a state – representing the species most commonly encountered by Keeley and Tuttle (1999) during a previous nationwide review. While maternity colonies are generally restricted to the Deep South, the species' range is expanding northward into western North Carolina, eastern Tennessee, and Virginia (McCracken et al. 2018). This bat readily uses bridges and forms large aggregations making it easy to detect. The potential presence of this and several other species (especially the little brown bat) that readily use bridges likely represents an important variable the current analysis could not accurately capture.

The best structural indicator of bat use is the presence of channel beams; one publication reported 78 of 113 channel beam bridges in North Carolina had bats (McDonnell 2001). Other important structural types included I-beam, and T-beam bridges – variables that prove key when the model was rerun excluding channel beam bridges. These bridge types, like parallel box beams identified by Keeley and Tuttle (1999), provide bats a variety of roost spaces. Conversely, bats virtually never use flat bottoms of slab-bridges, both designs providing little refuge. Similarly, most culverts provide little bat habitat, could potentially flood and kill bats (the smaller the culvert the more likely this is true), and so, are typically avoided by bats. However, interviews with several DOTs clearly indicated abnormally long culverts provide a cave-like habitat that bats will use. Notably, a publication became available after our analysis that indicates very long culverts (especially box culverts) are important winter habitat for bats in Mississippi (Rosamond et al. 2018).

Bats appeared to avoid roosting in steel bridges, but otherwise showed no preference for building material. A preference for concrete bridges was reported by Keeley and Tuttle (1999) and Bektas et al. (2018), but not detected when the nation-wide data was analyzed. Bektas et al. (2018) also indicated bridges constructed of concrete and steel were preferentially used, but authors who contributed to the nationwide data set likely lumped such bridges in with those constructed entirely of concrete. Results should likely be interpreted as concrete bridges are only valuable for bats if roosting space is available on the bridges. The interpretation indicates retrofitting slab-style, concrete bridges with roosting structures holds substantial promise.

A consistent problem with the analyses was an inability to extract meaningful variables from published studies, designed, implemented, documented, analyzed, and reported to address varying, and not always 100% compatible, hypotheses. Bektas et al. (2018) found more bats used prestressed concrete continuous, prestressed concrete, or steel continuous structures, findings that attest to a kind of detailed and high quality data that are poorly represented in the literature. Bektas et al. (2018) also used a variety of bridge dimensions and local habitat data to determine probability of bat presence. Detailed data were not published and only obtainable if each bridge location was known, and that was beyond the scope of this work effort. Finally, the literature indicates bats regularly use expansion cracks (Davis and Cockrum 1963, Fraze and Wilkins 1990, Keeley and Tuttle 1999, Trousdale and Beckett 2002, Diamond and Diamond 2003, Feldhamer et al. 2003, Trousdale et al. 2008, Amorim et al. 2013, Martinez et al. 2015, Sasse 2016), but data on the presence and extent of expansion cracks (and other crevices) were not typically available.

4.4.2 Data Provided by the Minnesota DOT

Analysis of data from the Minnesota DOT provided results similar to that seen in previous large-scale analyses of bats using bridges (Keeley and Tuttle 1999, Bektas et al. 2018), and fills many data gaps associated with the meta-analysis. The Minnesota DOT data indicate bats show a clear preference for large bridges where a concrete roadbed is suspended above a waterway by prestressed or precast concrete beams. Assuming the preference for prestressed or precast concrete beams is related to the presence of potential roosting habitat, the potential for providing bat habitat via retrofitting bat roosts to other large concrete bridges that cross large waterways becomes apparent. In particular, retrofitting roosts to bridges where concrete road decks are supported by concrete slabs or steel I-beams appears to offer numerous opportunities to attract roosting bats.

Notably, the DOTs and Departments of Natural Resources in Minnesota and Wisconsin recently completed mitigation aimed at replacing bat habitat lost when bridges carrying Interstate 95 across the Mississippi River (which is also the border between states, C. Smith and H. Karaakka, personal communication) were replaced. Mitigation efforts appear successful and include both the installation of bat boxes and the selection of a bat-friendly bridge design.

4.4.2.1 Value of Data Collected During Structural Assessments

Data collected during structural assessments would not be available had the northern long-eared bat not received protection under the ESA. In response to the listing and a resulting Biological Opinion (USFWS 2016b) mandating bridge inspections for bats, Minnesota began requiring collection of information on bats in bridges and culverts during engineers' and maintenance workers' routine inspections. Interviews with other states indicate the same practice is becoming common in other states (including Ohio, Kentucky, Indiana, Illinois, and Arkansas). The approach dramatically changes and augments data currently available, thus facilitating an understanding of why bats choose (or avoid) particular bridges. Data provided by the Minnesota DOT structural assessment provides presence/absence data from more than 14.000 bridges in one state as opposed to data from less than 4,000 bridges in 12 states that were included in the meta-analysis. The data set obtained from Minnesota DOT is in fact larger by an order of magnitude than previous large data sets (Keeley and Tuttle 1999, Bektas et al. 2018). Not only representing largest data set analyzed, the Minnesota data set also contains a wide variety of bridge types, coordinates of each bridge, multiple details about the bridge, and bridges spread across the state. Similar data sets in other states are considered privileged data when they contain information on the presence of protected species.

4.4.2.2 Challenges of Data Collected During Structural Assessments

In the process of providing data, C. Smith of Minnesota DOT also provided insight into potential sources of error associated with the data set. During follow-up surveys, he noted evidence of bats at every bridge where inspectors identified bat presence. Although no formal analysis was completed, follow-up visits indicate surveyors occasionally overlooked limited bat use. These observations are consistent with comments made by other DOTs, wildlife agencies, and experience of the research team. Skilled observers sometimes overlook instances of bat use of a structure when it's only used at night or bat signs are hidden in areas unavailable to the survey team (Civjan et al. 2017). If the source of error is substantial, then presence-only statistical techniques should be considered. In this case, the potential error is considered less important than the increased power of comparing likely absences.

In Minnesota, biologists complete follow-up visits on bridges where species identification is important (C. Smith, personal communication). Smaller and more detailed, the follow-up data set was not available to the current study's researchers. Access to such data typically requires a data-sharing agreement among the researcher, the DOT, and often the state natural resource or wildlife agency. Such data agreements may take months to implement.

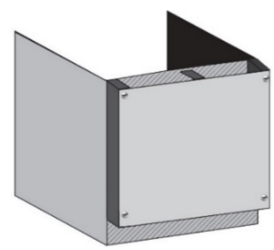
4.4.3 Important Factors Not Considered

Large-scale analyses such as those reported in this section are greatly limited by data that is available. Challenges encountered during completion of a review such as this include a the lack of detail in many publications and other sources reviewed. Most importantly, accessible information does not always provide data on how bats are using a particular bridge. When the primary goal is focused on determining types of structures associated with bat use, studies universally conclude that appropriate spaces for roosting are critical to a bridge's potential for bat use. As noted by previous authors, such appropriate roosting spaces may include cracks (Keeley and Tuttle 1999, Adam and Hayes 2000, Lance et al. 2001, McDonnell 2001, Trousdale and Beckett 2002, Diamond and Diamond 2003, Feldhamer et al. 2003, Keeley and Keeley 2004, Ferrara and Leberg 2005a; b, Celuch and Sevcik 2008, Trousdale 2008, BCI 2011, Amorim et al. 2013, Martinez et al. 2015, Sasse 2016, Civjan et al. 2017). Cracks occur in expansion joints or areas where two or more structural components meet. Bridge designs providing suitable cracks include box beam and channel beam bridges as well as almost any type of bridge where joins are not sealed and are frequented as day roosts of cave- and tree-roosting bats. Also important are protected open spaces that mimic caves and hollow trees (Keeley and Tuttle 1999, Adam and Hayes 2000, McDonnell 2001, Johnson et al. 2002, Kiser et al. 2002, Keeley and Keeley 2004, Trousdale and Beckett 2004, Bennett 2005, Bennett et al. 2008, Trousdale 2008, Trousdale et al. 2008, Willis et al. 2009, Amorim et al. 2013, Zara Environmental 2013, Cervone and Yeager 2016). Beams of bridges, where a structural element (such as an I- or T-beam) lies below and supports the road deck, create protected open space and are heavily used during the day by big-eared bats in the south and west, and by very large colonies of Brazilian free-tailed bats. Bridges also trap heat and provide opportunities for night-roosting bats (Perlmeter 1996, Adam and Hayes 2000, Johnson et al. 2002, Kiser et al. 2002, Gore and Studenroth 2005, Geluso et al. 2018). Also noteworthy is the cavern-like environment described by Cervone and Yeager (2016). The site they described apparently served as a migratory stop-over location for multiple species and was even used as a hibernaculum. As noted previously, very long culverts (especially box culverts conveying water under Interstate Highways) may create a cave-like environment used by some species as a hibernaculum, especially in areas where few caves are available (Sandel et al. 2001, Slider and Kurta 2011, Rosamond et al. 2018).

4.4.4 Potential for Future Mitigation

This document serves as a guide for identifying cases where unsuitable roosts can be successfully modified to create bat habitat. The best option for rapidly increasing bat habitat under bridges includes retrofitting artificial roosts to the bottom of large bridges that support a concrete road deck and that cross large waterways. Artificial structures should contain vertical cracks (as occur in a typical bat box) and protected open space. The latter could likely be simulated by placing three-sided containers (Figure 9) against the midpoint of support pillars on slab-style bridges. The design creates a relatively large hollow space but still allows bats direct contact with the bridge itself, which is important as a source of warmth (Smith and Stevenson 2013). Such structures would provide habitat for species that use protected open space, and (as illustrated) space could be added to the end to allow use by crack and crevice-roosting bats.

Figure 9. Three-sided bat box.



5.0 Review of Artificial Roost Designs

5.1 Introduction

For more than a century, free-standing artificial roosts (bat boxes and other habitats) have been used to create habitat for bats (Storer 1926), but successfully incorporating artificial roosts in mitigation efforts remains problematic (Whitaker et al. 2006, Sparks et al. 2009, Tuttle et al. 2013, Mering and Chambers 2014, Rueegger 2016, Griffiths et al. 2017a). To address this challenge, the research team planned a two-tiered analysis strategy similar to that completed in the Comparison of Bridge Designs effort in Section 4.0. The first analysis focused on data contained in published literature, while the second focused on previously unpublished data with potential to provide new insights. The literature review revealed three reviews published within the past five years. Attempts to document additional new studies met with resistance from researchers, often unable or unwilling to share data in a format suitable for analysis. Nonetheless, the search yielded several important observations that provide valuable insight associated with techniques used to design and implement a successful mitigation policy.

Based on available data, a successful mitigation effort must account for 1) the underlying physiology of the targeted bat species, which varies depending on seasonality, gender, and reproductive condition; 2) the behavior of targeted bat species, which also varies depending on seasonality, gender, and reproductive condition; and 3) implementation of a monitoring program with a reasonable chance of detecting success. Additionally, development of a national database of roosting types that can be used to evaluate successes and failures without revealing the locations of specific projects or roosts is imperative.

5.2 Methods

Data for artificial roost analysis came from the Literature Review completed in Section 2.0 and data obtained through the questionnaire and subsequent analyses in Section 3.0.

5.2.1 Data Analysis

Artificial roost data obtained from both published literature and survey efforts revealed widely scattered data sources inappropriate for conducting detailed statistical analyses. Further, the literature contains three separate reviews of this same literature base (Tuttle et al. 2013, Mering and Chambers 2014, Rueegger 2016).

The review from Tuttle et al. (2013) is aimed at the general public, but contains data on bat boxes and observations obtained from informal experiences from Bat Conservation International's internal database. The document contains bat house plans and anecdotes to communicate to bat box builders the reasons certain techniques are successful and how to incorporate successful techniques into their designs. Criteria covered by Tuttle et al. (2013) include box design, construction materials, wood treatment, sun exposure, surrounding habitat, mounting substrate, predator and pest avoidance, maintenance, and consideration of regional variation. Furthermore, Tuttle et al. (2013) provide factors that influence high occupancy rates and how those factors compare among common North American bat species.

Mering and Chambers (2014) reviewed data from 47 publications regarding the use of artificial bat roosts and incorporated these data to provide suggestions for improved roost designs. They found different authors provide a wide array of data with few studies directly comparing criteria that make artificial bat roosts successful (Mering and Chambers 2014). Thus, Mering and Chambers (2014) concluded the literature does not point to any specific criteria for general success of artificial bat roosts. However, they find most boxes are designed to mimic natural roosts of bat species in family Vespertilionidae and suggest that species-specific roost designs may be more successful than general designs (Mering and Chambers 2014).

Rueegger (2016) reviewed data from 109 publications that use artificial roosts to determine factors that influence effectiveness of artificial roosts. Like Mering and Chambers (2014), Rueegger (2016) found little conclusive evidence of specific factors that are important for general success of artificial roost designs. Rueegger (2016) found that boxes deployed on the landscape in clusters with variations in design are likely to provide a variety of microclimates from which bats can select. Furthermore, use of boxes increased over time and when species-specific designs were used (Rueegger 2016). Rueegger (2016) concluded artificial bat roosts are not sufficient replacements for natural roosts because artificial roosts rarely attract hibernating bats or maternity colonies.

Data obtained during the questionnaire and follow-up interviews are consistent with the findings of the reviews, but also indicate several recurring problems with how stand-alone artificial bat roosts are applied to both research questions and practical efforts to manage bats. As such, the remainder of this section focuses on issues identified during the questionnaires and follow-up interviews.

5.3 Results and Discussion

Table 1 references 50 publications that identify bats using bat boxes and similar structures. Thirty-four publications (Table 7) assessed 10,391 structures comprising dozens of designs and built principally of wood, woodcement, and synthetic materials. Few publications explicitly stated which designs had success or provided occupancy rates for compared designs. Due to variations in success reporting and highly variable box designs, a large-scale comparative analysis could not be performed on data extracted from publications; rather, conclusions from publication studies were analyzed to inform practices in box design.

Most of the bats targeted by stand-alone artificial roosts naturally roost in trees, rock crevices, and caves. Starting in the mid-1990s, the advent of radio-transmitters small enough to attach to bats supported an explosion of bat roosting ecology studies that revealed several key patterns among bats (Lewis 1995, Kalcounis-Rüppell et al. 2005, Barclay and Kurta 2007). First, bats preferentially select sites with suitable microclimates. Second, tree and crevice-roosting bats regularly and naturally move among roosts. Third, changes in reproductive conditions drive bats to select different microclimates (and thus different roosts) at different times of the year.

5.3.1 Unusual Characteristics of Chiropteran Physiology

Although bats are mammals, they rely heavily on environmental temperatures to control body temperatures. This simple observation means that effective roosts must provide a suitable microclimate for the target bat species and suitable conditions may change and vary over the course of a year. Microclimate within a roost is affected by roost construction materials, its placement on the landscape, and bat behaviors. Despite the importance of

Table 7. Literature reviewed for this task.

Citation	Title	Number of Boxes	Types of Boxes
(Chambers et al. 2002)	Use of artificial roosts by forest dwelling bats in northern Arizona	10 10	Resin Wood
(Kerth et al. 2000)	Day roost selection in female Bechstein's bats (*Myotis bechsteinii*) a field experiment to determine the influence of roost temperature	75	Woodcement
(Brittingham and Williams 2000)	Bat boxes as alternative roosts for displaced bat maternity colonies	30	Wood
(White 2004)	Factors affecting bat house occupancy in Colorado	95	Variable
(Whitaker et al. 2006)	Use of artificial roost structures by bats at the Indianapolis International Airport	3204	9 wood design types
(Carter et al. 2001)	Notes on summer roosting of Indiana bats	2	Wood
(Keeley and Tuttle 1999)	Bats in American bridges	-	2 wood designs on bridges
(Ritzi et al. 2005)	Use of bat boxes by a maternity colony of Indiana myotis (*Myotis sodalis*)	3204	9 wood design types
(Bartonicka and Řehák 2007)	Influence of the microclimate of bat boxes on their occupation by the soprano pipistrelle *Pipistrellus pygmaeus*: possible cause of roost switching	4	Wood
(Agnelli et al. 2011)	Artificial roosts for bats: education and research. The "Be a bat's friend" project of the Natural History Museum of the University of Florence	-	Wood
(Reid et al. 2013)	Artificial bat roosts did not accelerate forest regeneration in abandoned pastures in southern Costa Rica	48	Wood & Woodcement
(Gumbert et al. 2013)	Artificial bark designed for roost use by Indiana bats (*Myotis sodalis*)	21	Polyurethane
(Adams et al. 2015)	Success of BrandenBark™, an artificial roost structure designed for use by Indiana bats (*Myotis sodalis*)	69	Polyurethane
(Kaarakka 2017)	Roost monitoring report	-	Variable

Citation	Title	Number of Boxes	Types of Boxes
(Mering and Chambers 2012)	Artificial roosts for tree-roosting bats in northern Arizona	52 52	Wood Resin
(Arnett and Hayes 2000)	Bat use of roosting boxes installed under flat-bottom bridges in Western Oregon	15	Wood
(Diamond et al. 2015)	Population characteristics of big brown bat and Arizona Myotis using artificial roosting structures in northern Arizona	576	Wood
(Neilson and Fenton 1994)	Responses of little brown myotis to exclusion and to bat houses	43	Wood
(Dillingham et al. 2003)	Two environmental factors that influence usage of bat houses in managed forest of Southwest Oregon	48	Wood
(Hoeh and O'Keefe 2015)	Social behavior of Indiana bats selecting among artificial roosts	6 3	Wood Polyurethane
(Hoeh et al. 2018)	In artificial roost comparison, bats show preference for rocket box style.	18	Wood Polyurethane
(Kasprzyk and Ruczynski 2007)	The structure of bat communities roosting in bird nest boxes in two pine monocultures in Poland	187 1963	Woodcement Wood
(Long et al. 2006)	Well-placed bat houses can attract bats to Central Valley farms	186	Wood
(Ciechanowski 2005)	Utilization of artificial shelters by bats (Chiroptera) in three different types of forest	102	Wood
(Flaquer et al. 2005)	The value of bat-boxes in the conservation of *Pipistrellus pygmaeus* in wetland rice paddies	69	Wood
(Irvine and Bender 1995)	Initial results from bat roosting boxes at Organ Pipes National Park	10	Wood
(Threlfall et al. 2013)	Odour cues influence predation risk at artificial bat roosts in urban bushland	90	-
(Johnston 2005)	Recreating battered bat roosts	1	Wood in bridge
(Griffiths et al. 2017a)	Bat boxes are not a silver bullet conservation tool	126	-
(Griffiths et al. 2017b)	Surface reflectance drives nest box temperature profiles and thermal suitability for target wildlife	72	Wood

Citation	Title	Number of Boxes	Types of Boxes
(Rueegger 2016)	Bat boxes — a review of their use and application, past, present and future	Review	-
(Mering and Chambers 2014)	Thinking outside the box: A review of artificial roosts for bats	Review	-

[1] Call numbers are included to allow rapid response to future requests for information and reference to materials that will be submitted as part of the project record

roost microclimate as a driver for roost selection by bats, studies of roosting bats rarely provide direct measurements of microclimates (Boyles 2007).

A notable exception to omission of microclimate measurements includes the work of Hoeh et al. (2018). The authors compared six replicates of three different previously successful roost designs in an area where multiple colonies of bats are known to use artificial roosts. Each roost type contained devices to remotely monitor temperatures. The authors then assessed roost use in light of known acceptable temperatures which they defined as those between freezing (32˚ F, 0˚ C) and temperatures assumed lethal 113˚ F (45˚ C). Findings indicate some common artificial roosts types can reach lethal temperatures in summer. In this study, each rocket box provided a wide range of temperatures thus offering bats access to appropriate temperatures during a greater portion of summer.

5.3.2 Roost Switching

Telemetry studies of bats revealed bats occupying roosts other than caves and buildings move and change roosts every few days (Lewis 1995, Lewis 1996, Barclay and Kurta 2007). Bats may move between roosts to locate microclimates that are more suitable, avoid high densities of parasites, reduce predation, interact with colony mates, and as a means of learning about other roosting locations. Thus, even a well-used roost may not be occupied when checked.

5.3.3 Integrating Physiology into Choice of Construction Material

Various construction materials are used for artificial roosts, with selection directly associated to cost, longevity, and microclimatic conditions within a roost. Data collected during the on-line survey and research team experience both indicate that differing metrics of successful bat roosts may influence the appropriate type of roost for a particular task. The following presents a general outline of materials used for constructing artificial roosts, explains some costs and benefits of each material, and explains how each material caters to bat physiological needs.

Wooden Boxes

Most bat boxes in North America are constructed primarily of wood, largely due to low production cost and the belief wooden boxes mimic a wide variety of roosting habitats including: the space between exfoliating bark and the trunks of trees, hollow trees, cracks in trees, rock crevices, and anthropogenic roosts. Most boxes are relatively simple comprising a wooden box divided into roosting spaces by slats of wood. Larger boxes require more slats (creating more spaces or chambers) thus relative size is often described by the number of chambers. However, additional wooden boxes designed to create open space, and the rocket box designed to mimic sloughing bark also exist (Tuttle et al. 2013).

Wood has a relatively low thermal mass and does not maintain heat as well as other materials, such as concrete, that possess a higher thermal mass. Wooden boxes are likely to track ambient temperatures more closely than materials with higher thermal masses. For example, a wooden bat box is expected to heat quickly when exposed to solar radiation during the day, but also cools faster than materials, such as concrete, with a higher thermal mass. Bats also influence temperatures within the box with their own body heat, and by producing urine, guano, and other body secretions absorbed by the wood. Bat urine can change microclimates within the roost, serving as a source of evaporative cooling, increasing humidity, and increasing the thermal mass of the roost.

Depending on design and size, wooden bat boxes can cost as little as $5.00 for small, single-chamber boxes and range up to thousands of dollars for large wooden bat "condos". Unprotected wood is prone to decay and can require regular (sometimes annual) maintenance. Based on the experience of the authors, wooden boxes made of low cost materials (interior plywood or unprotected pine) may be unusable within three years, but structures made of cedar may last decades. Mounting techniques also present issues for consideration. For example, at the Indianapolis Airport boxes were constructed of decay resistant wood (cedar), but mounted to trees using pine boards, which often decayed within two years (Whitaker et al. 2006). In this case, pipe strap (perforated steel bands used to hold up pipes) mounted between the box and the pine board was an economical and effective solution.

Untreated wood (some treatments are toxic) is the best option for box construction, and areas intended for bat use should be coarse enough to allow bats to grasp the surface. Providing a suitable surface is often accomplished by using rough-cut lumber, adding screening, or by scouring the surface. Other issues associated with wooden boxes include the need to reseal spaces between boards and their attractiveness for use by drumming woodpeckers.

Simple wooden boxes are most valuable when the goal is providing bats with multiple cost-effective roosting options. Thermal properties can be modified by painting the structure a heat-absorbing color (which can also improve box longevity), by incorporating a thermal mass (such as a water vessel or other insulation), increasing the size of the box, and strategic placement of roosts (Tuttle et al. 2013, Griffiths et al. 2017b).

Finally, wooden boxes can be readily made by inexperienced wood workers such as local scout troops and other civic groups and play an important role for public education. Potential availability of volunteers provides a viable option for agencies impacted by limited budgets.

Metal Shell Boxes

Placing a metal shell around wooden slats is a common technique used to prevent decay. A well-known example (Butchkoski and Wayland 2004) comprises a 14-chamber metal shell design with a wooden interior and a corrosion-resistant aluminum exterior coated with black spray paint or powder coating to absorb heat and protect the metal from corrosion. These boxes can house up to 600 bats and remain in place more than a decade with only limited maintenance (insect nest removal and repainting).

A wooden box with a metal shell warms more quickly than a similar-sized wooden box due to the highly conductive nature of metal. Low thermal mass allows for easy absorption of energy and high conductivity allows heat to quickly pass into interior wooden baffles. In turn, the wooden baffles act like a similar-sized wooden box. Further, most metal-clad boxes are relatively large, thus increasing thermal stability.

Construction of metal shell boxes is more expensive and the exterior shell requires a skilled metalworker. However, the interior section can be constructed by less-skilled workers so long as the interior segment fits neatly inside the structure.

Metal shell boxes are regularly used in applications where the goal is to provide long-term habitat requiring minimal maintenance.

Resin Shell Boxes

Wooden baffles can be inserted into a plastic shell. Based on the results of Mering and Chambers (2012), plastic resin structures are expected to provide a microclimate similar to an all-wood design. The initial cost of a preconstructed resin box is approximately two times that of a similar all-wood structure (https://batmanagement.com/collections/bat-houses accessed on 10 September 2018). The manufacturer indicates resin-shelled boxes have a guaranteed survival of 15 years without requiring maintenance, whereas this website estimates wooden boxes require maintenance every three years. However, this statement overlooks the probability that some maintenance may be required to remove insect nests.

Resin Boxes (Artificial Bark)

Several efforts have been made to use plastic resin to create artificial bark (Chambers et al. 2002, Mering and Chambers 2012, Armstrong 2013, Gumbert et al. 2013, Adams et al. 2015, Hoeh et al. 2018). Most notably a product known as Brandenbark® (proprietary products included for completeness and not intended as an endorsement) has been used to attract colonies of endangered Indiana bats in areas of known species presence, but where natural roosts were declining in abundance (Gumbert et al. 2013, Adams et al. 2015). These roosts also attracted several other species of conservation concern (Gumbert et al. 2013, Adams et al. 2015) including the threatened northern long-eared bat; the little brown bat, then under review for listing due to rapid declines (Tinsley 2016), the tricolored bat, now under review for federal listing (Center for Biological Diversity and Defenders of Wildlife 2016, USFWS 2017), and the evening bat (*Nycticeius humeralis*), a species of concern in Kentucky (https://fw.ky.gov/Wildlife/Pages/Evening-Bat.aspx accessed on 10 September 2018).

In side-by side comparisons, resin roosts required less maintenance and were occupied by bats more rapidly than wooden boxes when both artificial roost types were mounted to trees and maintained a similar thermal environment (Mering and Chambers 2012). A second, side-by side comparison of similar-sized resin bark structures, three-chambered wooden boxes, and wooden rocket boxes revealed Indiana bat use of all three structure types. Rocket boxes received much greater use than the resin bark structures and the three-chambered boxes – a factor the authors correlated with a tendency to maintain appropriate thermal conditions. In particular, the resin bark structures became too hot in summer. An important caveat is that larger, commercially available resin bark roosts would be expected to have greater thermal inertia and less likely to reach such high temperatures

While the initial cost of wooden boxes is lower, resin boxes require less maintenance and are potentially more cost-effective over time (Chambers et al. 2002, Mering and Chambers 2012). While resin itself is not porous, resin bark is placed around wooden poles or on the sides of live trees which in turn absorbs moisture from the bats.

Woodcement

Woodcement is made by mixing cement and fine sawdust. It provides an alternative to wood and is longer lasting, waterproof, and has a higher thermal mass. Woodcement has had success attracting a variety of European bat species (Rueegger 2016), but is not widely used in North America. High thermal mass inhibits warming, but also slows cooling (i.e., boxes have high thermal inertia). Thermal inertia facilitates high internal roost temperatures during cool nights. Woodcement is porous and exhibits humidity conditions similar to wood.

Creating Dead Trees

For bats that roost in dead trees, killing trees to create roosts appears at first a direct route for creating habitat. Such efforts, along with moving some trees cut during construction, were components of mitigation efforts studied at the Indianapolis Airport (Whitaker et al. 2006), and are considered viable mitigation techniques for Indiana and northern long-eared bats (USFWS 2015). To date, the only cases where bats inhabited trees that had been intentionally killed were accidental in nature. Indiana bats on both the Hoosier National Forest (Brack et al. 2004) and Newport Chemical Depot (Brack and Whitaker 2006) were tracked to roosts in trees killed as part of Timber Stand Improvements conducted for silvicultural reasons. Similarly, Indiana and evening bats were often tracked to the "impact area" of Camp Atterbury, a military base where live-weapons training produced multiple dead trees (Whitaker et al. 2005). These "successes" should be tempered by the realization that none of the moved or killed trees were used by bats at the Indianapolis Airport (Whitaker et al. 2006), and questionnaire respondents also indicated a low success rate for this technique. Newly available data on the use of created snags by cavity-roosting birds over a 20-year period also indicate only limited success (Barry et al. 2018), suggesting snags created by managers do a poor job mimicking trees that die naturally. Notably, trees killed by other management activities such as prescribed fire can be extensively used (Boyles and Aubrey 2006, Ford et al. 2016).

Unusual Roost Designs

Several unusual roost types were created as part of experimental efforts to build better bat roosts. Whitaker et al. (2006) describe the largest and longest-running mitigation experiment using bat boxes in North America. The study included 3,204 roosts representing nine types and included typical wooden boxes ranging in size from tree-mounted, 3-chambered bat boxes to large stand-alone boxes similar to the Bat Condos now on the market (https://batmanagement.com/collections/bat-houses accessed on 10 September 2018).

Multiple experimental structures were included in the study such as tarpaper boxes, large 36-inch x 36-inch (0.9-m x 0.9-m) wooden boxes covered on the inside and out with tarpaper. The tarpaper provided nooks and crannies where bats could roost whereas the interior of the structure was open and resembled spaces found under bridges and used by some species. Simulated bark roosts included wrapping trees with tarpaper or plastic, wrapping trees with garlands of wooden shingles suspended by a wire, nailing small, one to three (depending on size), wooden shingles to the sides of trees, and using a hatchet to create a bark roost.

As noted by Whitaker et al. (2006), most of these efforts were unsuccessful because 1) roosts were placed in shaded locations, which failed to provide suitable microclimates; and, 2) most designs were easily damaged by winds and storms. Most bats were found in traditional boxes and Condos, although a few used shake garlands.

Notably, results of additional telemetry studies at the site identified occasional use of shake garlands, plastic skirts, and tarpaper boxes, and noted daily use of slat-style boxes (D. W. Sparks, Unpublished).

Additionally, Armstrong (2013) developed a roost type designed to mimic conditions found in an attic or barn by creating stand-alone roosts out of commercial car ports. Studies are ongoing, but to date these roosts are not occupied.

5.3.4 Other Factors Influencing Microclimate

Construction materials play an important role in determining a structure's response to environmental conditions. However, microclimate within the roost is also influenced by many other factors including local climatic conditions and how the roost is installed. Tuttle et al. (2013) provide many simple and informative points regarding techniques to influence the microclimate within an artificial roost. Providing bats an escape from high temperatures is a key issue in hot climates such as the Deep South or Central Valley of California (Long et al. 2006, Tuttle et al. 2013). Such efforts can include 1) shading bat boxes with a separate roof, 2) placing boxes on buildings, painting the boxes to reflect sun light, and 3) mounting boxes back to back on poles, providing access to a variety of conditions within and between the boxes. In the Central Valley of California, bat colonies preferentially occupied roosts mounted to buildings, with some shade, and within 0.25 mile (0.4 km) of surface water (Long et al. 2006).

Conversely, across much of the country, bats (especially maternity colonies) need roosts that maintain high temperatures. Two primary means of accomplishing this task include mounting bat boxes in areas with minimal shade and covering the outside with paint that absorbs solar radiation (often darker colors in a matte finish). Thus, roosts mounted to live trees typically have less success than those mounted in the open (Whitaker et al. 2006, Tuttle et al. 2013). In colder regions of the U.S., roosts facing south or east are most successful at attracting bat colonies (Dillingham et al. 2003, Mering and Chambers 2012). However, males and post-reproductive females may search out cooler roosts enabling the use of daily torpor (Humphrey et al. 1977, Kurta

2004). The change in behavior was likely the cause of high occupancy of the large Missouri Boxes used at the Indianapolis Airport (Whitaker et al. 2006). Roosts were occupied almost exclusively by males during early summer, but bats of all ages and genders occupied the roosts once juveniles became volant (DW Sparks Unpublished).

Griffiths et al. (2017b) measured temperatures in painted nest boxes for several species (including bats). Boxes were painted such that they reflected 5.9% (dark green), 64.4% (light green), and 90.3% (white) of the incoming solar radiation. Data were used to simulate thermal conditions within boxes throughout the year. Data indicated boxes pained the darker color became dangerously hot in high temperatures whereas white boxes were often at suboptimal temperatures. Placing boxes of different colors in different locations allows wildlife to select sites that provide appropriate microclimate for current conditions.

Finally, larger structures have a higher thermal mass than smaller structures constructed of the same material and thus heat and cool more slowly. Two recent review papers (Mering and Chambers 2014, Rueegger 2016) noted bat box dimensions are only rarely reported.

5.3.5 Landscape Factors

Artificial roosts placed in unsuitable landscapes have little chance of success. Bats require access to viable foraging and drinking habitat. Thus, artificial roosts in close proximity to both resources have a higher potential for occupation than those located far from such resources. For example, Long et al. (2006) noted that artificial roosts were used more frequently when within 0.25 mile (0.4 km) of a water source—a critical factor in dry portions of the country. Similarly, roosts eventually used by Indiana bats at the Indianapolis International Airport were positioned in the core of a conservation area, developed by placing created wetlands and replanting forests around a series of existing woodlands and waterways that, by design, became the focal point of foraging and roosting by local Indiana bats (Sparks et al. 2009). Resin bark structures placed in areas of known use by foraging Indiana bats were particularly successful at attracting the species (Gumbert et al. 2013, Adams et al. 2015). Roosting boxes have proven especially successful when targeted at locations where bat colonies are expected to lose roosts due to exclusion or natural decline of roosts (Neilson and Fenton 1994, Brittingham and Williams 2000, Whitaker et al. 2006, Gumbert et al. 2013, Adams et al. 2015).

Bats switch roosts every three to five days. As such, clusters of roost boxes have proven more likely to be occupied than scattered single structures. However, placing artificial roosts along travel corridors and near known or potential drinking sources provides an important opportunity for local bats to discover and use these roosts. In hindsight, roosts installed at the Indianapolis Airport would likely have been more successful had they been installed in the areas where reforestation was completed – a technique that may also have drawn bats into the restoration plantings (Whitaker et al. 2006).

5.3.6 Mimicking Natural Roosts

Several recent papers (Mering and Chambers 2014, Rueegger 2016, Griffiths et al. 2017a) directly noted the need for artificial roosts to target a particular species or at least bats that share similar roosting behaviors. For example, within the range of the Indiana bat, multiple roosts are specifically designed to mimic the sloughing bark used by roosting Indiana bats. As noted above, the large-scale study at the Indianapolis Airport combines multiple novel structures aimed at attracting this species (Whitaker et al. 2006). Subsequently, rocket boxes were designed around the concept of a roosting area space surrounding a central post (Carter 2002, Tuttle et al. 2013, Hoeh and O'Keefe 2015). In turn, this led to development of resin bark roosts where artificial bark is wrapped around an untreated utility pole resulting in a structure that, to people, visually resembles a roost used by Indiana bats (Gumbert et al. 2013, Adams et al. 2015). Similarly, several studies by the Chambers Lab at Northern Arizona University made use of artificial roosts painted to resemble the ponderosa pines on which they were mounted (Chambers et al. 2002, Mering and Chambers 2012). Griffiths et al. (2017a) noted that failure to properly target roosting behavior of a rare bat meant boxes were more likely occupied by species more generalized in their roosting behavior – an observation that potentially applies to prompt use of structures at the Indianapolis Airport by northern long-eared bats, a species considered roost generalists (Whitaker et al. 2006).

5.3.7 Time Until Occupancy

Multiple formal and informal studies show a lag time between artificial roost installation and bat use of the structures (Whitaker et al. 2006, Agnelli et al. 2011, Mering and Chambers 2012). This is true even in cases where all other variables were aligned for success. Typical experiences were described by staff of Texas (J. Young, Personal Communication) and Minnesota (C. Smith, Personal Communication) Departments of Transportation (DOT) and the Wisconsin Department of Natural Resources (DNR) Minnesota (H. Kaarakka, Personal Communication) during the questionnaire process. The Texas DOT described a bridge replacement project where bat boxes were used to rehouse a colony of Brazilian free-tailed bats living beneath the existing bridge. Wisconsin DNR and Minnesota DOT each noted a joint project where bat boxes were used to rehouse a colony of little brown bats that roosted between a pair of bridges where I-85 crosses the state border at the Mississippi River. In both cases, project biologists were experienced with using and installing bat boxes, and familiar with types of structures and mounting techniques most likely successful for use by species in those areas. Similarly, boxes were installed prior to construction, but several seasons elapsed before boxes were fully occupied. During intervening periods, bats were obviously roosting elsewhere. Based on the lag time between box installation and bat occupancy (Whitaker et al. 2006, Agnelli et al. 2011, Mering and Chambers 2012), the current mitigation guidance in West Virginia (USFWS 2015), where artificial roosts are installed and monitored across only two maternity seasons likely underestimate success in attracting bats.

5.3.8 Consider Potential Predators

Although no species of predator in North America specializes in hunting bats, an impressive list of species is known to prey upon them (Sparks et al. 2000). As such, stand-alone roosts must be high enough to allow bats to drop from their roosts to begin flying without capture by predators. Tuttle et al. (2013) recommend a minimum height of 10 to15 feet (3 to 4.6 m) above the ground, but this should be interpreted as above the surrounding vegetation. Agnelli et al. (2011) found bats were increasingly likely to occupy taller roosts, but Rueegger (2016) indicated box height was probably species-dependent and noted bats are likely to use low mounted boxes in the absence of other structures. Long et al. (2006) suggested the preference for building versus pole-mounted boxes was driven in large part by the thermal inertia of the building, and that pole-mounted boxes can also serve as raptor perches. Counter to this, DW Sparks (Unpublished) notes a large colony of little brown bats decimated when their barn roost was colonized by house cats (*Felis catus*). In this case, bat box installation some distance away from the barn was recommended. Bat boxes added to structures originally designed to attract roosting bald eagles (*Haliaeetus leucocephalus*) now contain little brown bats though the species has effectively disappeared from the surrounding landscape (ESI, Unpublished). As such, protection from predators should be addressed on a case-by-case basis.

6.0 Conclusions

To borrow from Griffiths et al. (2017a), a review of available data produces no “silver bullet” or simple answers to selecting an artificial roost that will work under all conditions for all species (Tuttle et al. 2013, Mering and Chambers 2014, Rueegger 2016). Successful mitigation efforts require a working understanding of the ecology of the target species and determination of techniques proven effective in the local area. Successful mitigation will often be both nuanced and specific to individual species and sites must be viewed in light of the sheer volume and complexity of information (and misinformation) about bat boxes available. While the Best Management Practices (BMP) Manual developed in concert with this report facilitates transportation professionals in addressing projects with respect to bats, the following issues should be addressed and considered prior to using artificial roosts to mitigate highway projects. The questions and observations that follow are designed to substantially improve the quality of a planned mitigation effort, and like the BMP Manual draw heavily on the research team’s experience developing and implementing mitigation efforts.

6.1 Is there a Target Species?

6.1.1 Mitigating Impacts to Rare or Specialized Species

Highway biologists are often tasked with attempting to mitigate loss of habitat for rare or specialized species potentially affected by a transportation project. If a target species has specialized roosting needs, it is important to remember the observation by Griffiths et al. (2017a), who noted most readily available artificial roosts attract only common species and thus have little value for rare species. All other recent reviews (Tuttle et al. 2013, Mering and Chambers 2014, Rueegger 2016) also noted the value of selecting an artificial roost appropriate to a species if one is targeted. If the target species does not have an extensive history of using artificial roosts, development of a new roosting structure may be necessary. In such cases, managers are encouraged to consider not only the appearance of the roost, but the microclimate used by bats and other landscape factors (Griffiths et al. 2017b). Notably, mitigation approaches used for highly specialized species are unlikely to be transferable to other species.

Where information about natural roosts or successful artificial roosts is limited, designing a study that compares multiple roost types within the same environment may be the best option – if such comparative studies are included, the monitoring component must be rigorous enough to make meaningful comparisons among roost types. Participants should approach the study with a willingness to implement adaptive management (Runge 2011, Organ et al. 2012, Williams and Brown 2012) where lessons are incorporated as they are learned. Adaptive management may result in multiple false starts and design changes prior to determining acceptable methods. Efforts to develop artificial roosts for Indiana bats have been on-going for more than 20 years with success coming in multiple forms and places (Salyers et al. 1996, Whitaker et al. 2006, Armstrong 2013, Gumbert et al. 2013, Adams et al. 2015, Hoeh and O'Keefe 2015, Hoeh et al. 2018). In such situations, all participants must determine what constitutes success, whether it is completion of the study or the use of the structures by bats.

6.1.2 When Targeting Locally Common Species

In some cases, mitigation goals include providing alternate habitat for colonies of common species displaced by a transportation project, typically associated with repair or replacement of bridges containing bat colonies, but also apply when buildings used by bats are removed (Neilson and Fenton 1994, Brittingham and Williams 2000). In such cases, Tuttle et al. (2013) is an excellent source of guidance often supplemented with information from local experts in academia, consultants that specialize in bats, or state resource agencies. For example, the Wisconsin DNR conducts extensive outreach and education efforts associated with roosting bats and publishes results in an annual report (Kaarakka 2017). Gathered information was critical to the successful relocation of a colony of little brown bats occupying bridges along the Wisconsin and Minnesota border, showing external assistance can be used to “fine-tune” mitigation for target species.

6.1.3 When Trying to Provide Habitat for Bats in General

Where objectives include providing habitat for any variety of bats, information contained in Tuttle et al. (2013) and supplemented by local expertise from academia, consultants that specialize in bats, or the DNR is most appropriate. The best option primarily includes providing habitat aimed at common bat species. However, in some cases, subtle differences require consideration in the approach used to make bat boxes attractive to multiple common species as opposed to one species in particular.

6.2 How will Success and Failure be Measured?

Responses to the questionnaire indicate success of bat mitigation (including artificial roosts) is defined and evaluated by a wide variety of criteria. Thirty-eight percent of respondents indicated mitigation is judged a success regardless of whether or not it attract bats, and an additional 37% of respondents indicated the simple presence of bats was considered a success.

A follow-up question indicated 63% of respondents cooperate with another entity regarding bat mitigation efforts. Eighty-two percent of the time the cooperator works for a natural resource or wildlife agency, and 27% of these cooperators use different definitions of success. In all cases the cooperator required bat presence for a project to be considered successful.

Questions regarding mitigation success were included in the survey based on repeated experiences of the research team (composed of consultants and academic biologists). Two consistent patterns were revealed.

First, the definition of successful mitigation is often inconsistent between project proponents and natural resource and wildlife agencies. Project proponents (in multiple industries) tend to view bat mitigation as a potential barrier to project completion. Thus, successful mitigation allows the project to move forward. Natural resource and wildlife agencies tend to define successful mitigation as providing tangible benefits – regarding artificial roosts, defining benefits entails a sliding scale where occasional use by a few bats is good, but the actual goal is regular use by a target species.

The second pattern is for definitions of success to further diverge once artificial roosts are deployed. Project proponents in many industries often attempt to escape or reduce ongoing monitoring and maintenance costs once a project is operational. Conversely, resource agencies become concerned when artificial roosts are not immediately filled with rare bats. Overcoming these changing definitions of success became a key challenge during conservation efforts at the Indianapolis Airport (Sparks et al. 2009).

Also observed was a nearly opposite dichotomy when habitat restoration or protection occurs, and this dichotomy was also noted by some respondents to the questionnaire. Natural resource and wildlife agencies tend to define success as acres of land protected or restored. In most cases, funding is provided to the resource agencies or a designated partner and used to locate, purchase, protect, restore, and eventually manage land. Over time, project proponents tend to question whether such mitigation is beneficial to target species.

6.2.1 Define Objective Metrics of Success and Failure Prior to Implementing Mitigation Efforts

Defining success and failure metrics should involve all partners and include a specific discussion of incorporating differing mission statements of each cooperator.

6.2.2 Ensure that the Mitigation, Monitoring, and Maintenance Goals are Consistent with the Impacts being Mitigated

Artificial Roosts as Temporary Habitat

Inclusion of artificial roosts in multiple projects is effective in addressing a temporary loss of roost trees associated with construction. Roosts are primarily intended to address a very local and short-term (one to three years) loss of habitat. Implementation of short-term roosts, includes low cost (typically small boxes built of plywood) roosts with limited functionality/life expectations. Maintenance efforts are minimal and required monitoring efforts restricted to the period when bats need the boxes. Monitoring objectives include informing improvement mechanisms for implementation on future projects.

Artificial Roosts as Medium-term Habitat

Artificial roosts are primarily intended to serve as medium-term (1 to 10 years) habitat while longer-term restoration and preservation efforts are implemented and are often referenced as a bridge strategy, as the intent covers a short-term short-fall in available habitat. Monitoring and maintenance issues are likely important factors contributing to the long-term cost of the project. Using structures requiring minimal maintenance are the most cost-effective and maximize usefulness for bats. Required monitoring is expected to occur at regular intervals and implementation of corrective action (i.e., adaptive management) is necessary to maximize the value of roosts to the target bat species.

Artificial Roosts as Long-term Habitat

Where bats are permanently excluded from a roost such as a bridge or building, goals may include permanent habitat replacement and critical consideration of the need for long-term monitoring and maintenance. Monitoring and maintenance objectives potentially change over the life of such projects. For example, it is reasonable to expect relatively intense monitoring early in the effort and use of adaptive management to ensure and maximize use of structures by the intended bat species. Once roosts are occupied, monitoring can decline to irregular checks at appropriate times of year to ensure structures remain occupied and to address any maintenance issues that arise.

Roosts intended as permanent structures, such as those clad in metal or resin, have occasional maintenance and repair issues. Examples of such issues include: 1) storm damage, 2) removing nests of mud daubers (Family Sphecidae) and paper wasps (Family Vespidae) that can clog the roost, 3) acts of vandalism, 4) repainting metal shells, and 5) damage caused by other wildlife – especially woodchucks (*Marmota monax*).

6.2.3 Think Long-term, Even on Short-term Projects

As noted above, project proponents, including most transportation administrators, view mitigation efforts as a means to an end (i.e., building a project). Thus, on a project-by-project basis, quick simple mitigation is preferable. When portions of the effort are contracted separately, the result is often the use of the lowest cost roost that meets the requirements set forth by a resource agency. The approach can lead to subsequent increases in maintenance costs. Similarly, low-cost monitoring efforts that use construction staff or general biologists may overlook issues obvious to an experienced bat biologist. However, generalized staff may incorporate checking artificial roosts as part of their routine duties – thus greatly increasing the potential for detecting bat presence. All parties should be open to applying the lessons of adaptive management and view each project as an opportunity to improve future efforts. A commitment to collecting and (eventually) providing supporting data so that others can benefit from the effort is required.

6.2.4 Take Advantage of Unplanned and Irregular Monitoring

While it is most beneficial to determine the effectiveness of mitigation through involvement of experienced bat biologists at least once per year, an enormous benefit is recognized by completion of checks at other times as well.

Use of Other Staff and Community Science

Roost checks, by less experienced staff, whenever personnel are near a roost and the check does not detract from other responsibilities, may provide an opportunity for education and training. Similarly, natural resource and wildlife agencies in several states are sponsoring community science initiatives where interested naturalists complete checks of artificial roosts and potentially perform emergence counts. Potential benefits are enormous if individuals are guided to roosts created for mitigation.

Inexperienced observers at artificial roosts primarily follow the same pattern observed in bridge data obtained from Minnesota DOT (C. Smith, Personal Communication). No instances of inexperienced observers wrongly reporting bats in roost boxes (i.e., false positive) occurred. There were instances of inexperienced observers overlooking roosting bats (i.e., false negative), especially when boxes are also occupied by mud daubers. However, there is no chance of detecting bats if the structures are not checked.

Use of Guano Screens

Guano screens installed beneath bat boxes offer an inexpensive means of passively monitoring bat box use. Bats change roosts every few days, thus the chance of observing use during a one-time visit is relatively low. Conversely, screens are left in place for weeks or months at a time, and any guano recovered is subjected to molecular analysis to determine the species of bat(s) that used the roost. The amount of guano that accumulates over a known period of time provides a crude measure of the number of bats present (Fraze and Wilkins 1990, Duchamp et al. 2010), and DNA extracted from guano obtained under bat boxes was used to identify individual Indiana bats as part of a molecular capture-recapture study (Oyler-McCance et al. 2018).

6.3 When will Bats Need Mitigation?

One of the few areas of agreement among available papers is that bats take time to occupy artificial roosts (Whitaker et al. 2006, Agnelli et al. 2011, Mering and Chambers 2012). Several participants in follow-up calls also noted that taking time to plan mitigation could lead to substantially decreased costs. Mitigation should be planned well in advance and installed at least one year before it is needed.

6.4 How does White-nose Syndrome Change the Equation?

White Nose Syndrome is a fungal disease that has decimated populations of cave-hibernating bats from the Atlantic Coast to the Rocky Mountains. Migrating bats can move spores of the fungus many miles (Minnis and Lindner 2013, Miller-Butterworth et al. 2014, Heffernan and Turner 2016), and the pathogen (*Pseudogymnoascus destructans*) is part of a family of soil fungi (Minnis and Lindner 2013) which does not need a bat host to survive. Thus, used bat boxes should not be moved from one area to another and the oft-recommended process of treating new bat boxes with guano should typically be avoided. Finally, artificial roosts may have some benefit if they provide shelter that allows bats to become active sooner as most bats that make it to their summer range are able to heal and survive (Reichard and Kunz 2009).

6.5 Areas of Needed Improvement and Research

The current project identified a need for change regarding several areas of research into the use of artificial roosts.

Creation of a National Database

A portion of this study was intended to analyze all available data (including those from unpublished sources) and develop guidance for installing structures that are most suitable for widespread use. Despite targeting questionnaires at individuals and organizations actively involved in the use of artificial roosts, efforts to obtain usable unpublished data were largely unsuccessful. Specific challenges encountered included 1) most natural resource and wildlife agencies closely guard data that identify the location of protected species, 2) natural resource and wildlife agencies in multiple states indicated a willingness to provide data but lacked find funding to database the information; and 3) several studies using artificial roosts are incomplete. An internal review of projects completed by the research team noted multiple cases where artificial roosts are widely used but monitoring data are not yet available.

Based on the observations above, creation of a national database may assuage some of the limitations potentially encountered through the current state-by-state paradigm. A partial database is maintained by Bat Conservation International, and could serve as the initial foundation for development. If appropriately managed, disclosure of exact roosting locations of rare or protected species would not be necessary, but data could be collected across a large portion of the country.

Greater Emphasis on Long-term Controlled Experiments

As noted in two recent reviews of the academic literature (Mering and Chambers 2014, Rueegger 2016), data on artificial roosts are widely spread and only a few studies include comparison of multiple roost types under controlled circumstances. An important exception to this trend includes papers by the Chambers Lab at Northern Arizona University associated with several controlled experiments evaluating the value of artificial roosts as habitat in forested landscapes (Chambers et al. 2002, Mering and Chambers 2012). For example, two papers (Gumbert et al. 2013, Adams et al. 2015) describing the value of resin bark note a much higher rate of use than structures studied by Whitaker et al. (2006) without noting a key observation of the Whitaker et al. paper – the roosts in that study were placed in woodlands because the value of solar exposure was not yet understood. Subsequent side-by-side comparisons at the site of the Whitaker et al. study revealed a preference for rocket boxes over a modified resin bark roost (Hoeh and O'Keefe 2015, Hoeh et al. 2018). A significant contributor to the lack of side-by-side comparisons is a natural desire on the part of bat box manufacturers to distinguish their product from others on the market. As a result, manufacturer claims have not been extensively or statistically tested.

Incorporation of Biophysiological Ecology

Throughout this report, the importance of microclimate within an artificial roost has been highlighted. However, this is another relatively poorly researched area. Tuttle et al. (2013) noted that maternity colonies need temperatures between 80° and 100° F (26-38˚ C), likely based on the experience of Dr. Tuttle. This is a reasonable rule of thumb, but the future researchers are encouraged to take a more formal approach to this topic. Future researchers would also be wise to follow many of the procedures used by Hoeh et al. (2018) who conducted replicated studies of clusters of artificial roosts in an area where bats were known to use artificial roosts. These studies included simultaneous comparison of temperatures in both occupied and unoccupied roosts and used multiple techniques to assess the presence and identification of bats within the roosts.

Efforts of authors providing information on temperature within artificial roosts are commendable. However, microclimate is more complex than simple temperatures – especially when target species partially control temperatures by changing roosts, changing thermogenesis, or even using urine for evaporative cooling. There is a strong need for greater application of operative temperature models such as those described by Bakken and colleagues (Bakken et al. 1981, Bakken et al. 1985, Bakken 1989, Bakken 1992, Bakken et al. 2001). In particular the research team encourages authors to expand on the Hoeh et al. (2018) study by considering both lethal temperatures (above 113˚ F [45˚ C]) and preferred temperatures of 80˚ to 100˚ F (26-38˚ C) as recommended by Tuttle et al. (2013).

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APPENDIX A
RESPONSES TO QUESTIONNAIRE

Fifty-six completed responses and six partially completed were received. Since none of the partially completed responses were duplicate responses, they were included in the analysis. Respondents from California represented 19 of the 62 responses, but nationwide results were only skewed by the uneven data set for questions related to regulations or definitions of mitigation success.

For clarity, each question is repeated below followed by a summary of responses from completed surveys. In some cases, the respondents were provided with space to supply additional responses, including some open-ended questions. Responses are repeated below and closely parallel the original response. Where appropriate, responses were edited to improve clarity by removing obvious typographical errors and misspellings.

1.0 Step 1: Identify level of activity in state

This first set of questions is designed to identify the level of activity by your organization or agency.

1. In what state do you primarily work?

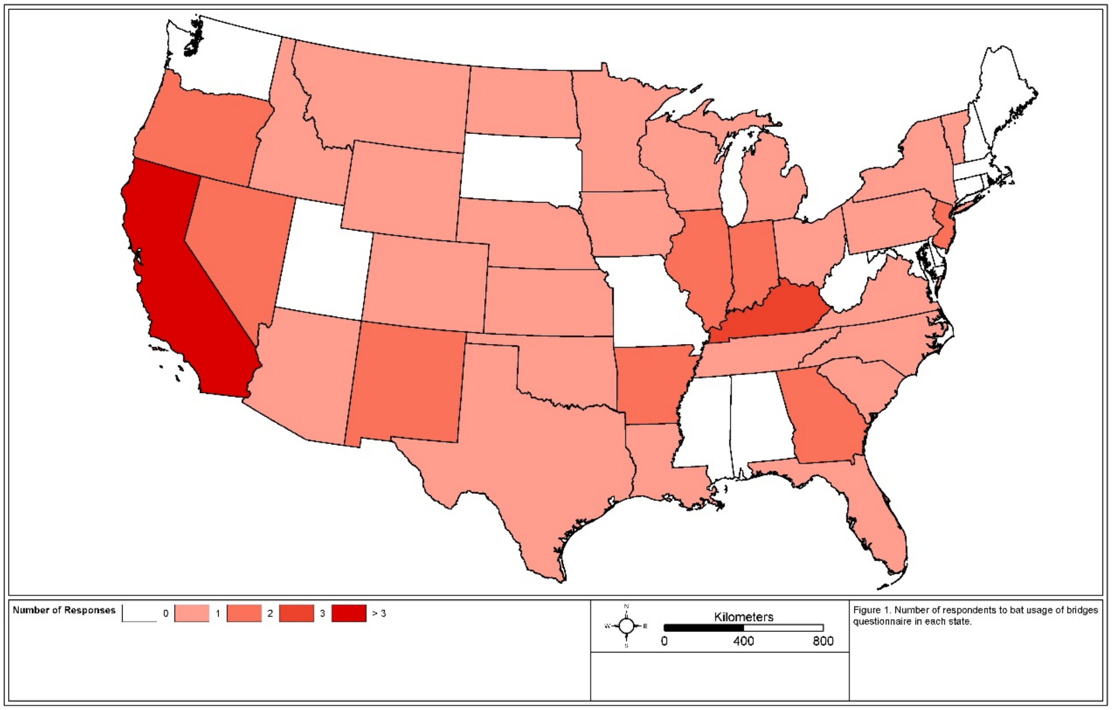
Sixty-two participants reported work from the following 34 states: Arizona, Arkansas, California, Colorado, Florida, Georgia, Idaho, Illinois, Indiana, Iowa, Kansas, Kentucky, Louisiana, Michigan, Minnesota, Montana, Nebraska, Nevada, New Jersey, New Mexico, New York, North Carolina, North Dakota, Ohio, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Vermont, Virginia, Wisconsin, and Wyoming. Most states produced a single response, although multiple responses were received from people working in Arkansas, California, Georgia, Illinois, Indiana, Kentucky, New Jersey, New Mexico, and Oregon (Figure 1).

2. Within this state, is there a region where you focus your work?

Six of 41 participants restricted their activities to a particular region in the state:

- Arkansas: Ozarks primarily, but work is statewide;
- California: Most California participants said they were restricted to a region in the state;
- Indiana: Indianapolis Airport Region;
- Kentucky: Jackson Purchase CA 1990-1993;
- Nevada: Northern Half of Nevada; and
- South Carolina: Upstate.

Figure 1. Number of respondents to bat usage of bridges questionnaire in each state.



3. **What best defines your role?**

Thirty-nine participants in the survey are biologists employed by a transportation agency. Additionally, 6 transportation professionals (not biologists), 4 academic biologists, 2 consultants, and 11 employees of natural resource or wildlife agencies responded.

4. **In your state, how often are existing highway structures inspected for bats by DOT staff, consultants, or academic biologists?**

Fifty-seven of 62 respondents were aware of efforts to locate bats in existing highway infrastructure. A state breakdown of these results can be seen in Table 1 and Figure 2. Inspections that are part of routine inspection/maintenance programs were the least common:

- Irregularly and unplanned (19 respondents);
- Part of our routine inspection/maintenance program (12 respondents); and
- Structures are routinely checked before any repairs or removals (26 respondents).

5. **What happens when bats are found during a project? Please provide an approximate percentage of the time a particular scenario applies.**

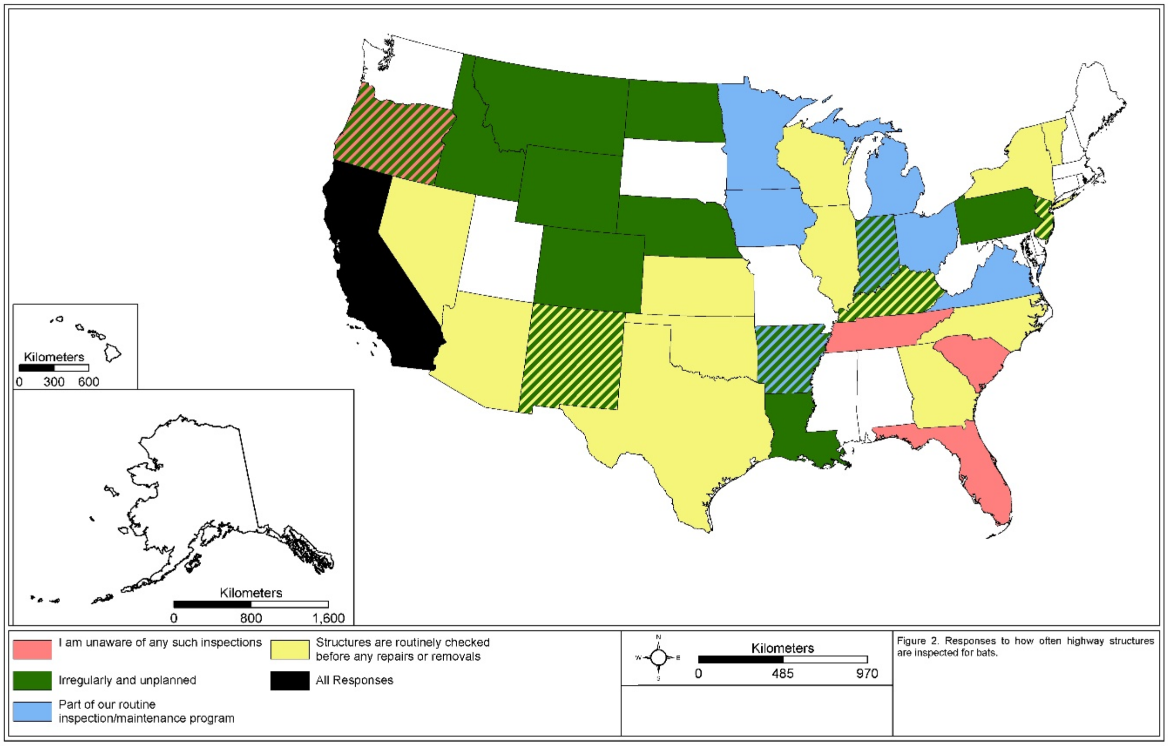
When bats are found during a project, organizations most often (48% of the time) collect data on bats present and consult with a natural resources or wildlife agency

Table 1: State-specific Responses to Questionnaire.

State	In your state, how often are existing highway structures inspected for bats by DOT staff, consultants, or academic biologists? NOTE: EACH RECIPIENT COULD CHOOSE ONE OPTION				What happens when bats are found during a project? Please provide an approximate percentage of the time a particular scenario applies. NOTE: EACH RECIPIENT COULD APPLY A PERCENT OCCURRENCE RESPONSE TO EACH OF ONE OR MORE CATEGORIES			
	I am unaware of any such inspections	Irregularly and unplanned	Part of our routine inspection/maintenance program	Structures are routinely checked before any repairs or removals	Move forward with the project without regard to the bats	Wait for bats to leave for the season (seasonal avoidance) and proceed with construction or building the bats out (i.e., exclusion)	Move forward with the project after ensuring the bats are protected	Obtain data about the type of bats that are present and consult with natural resource agencies
Arizona				1	0	90	10	0
Arkansas		1	1		0	0	12.5	87.5
California	1	4	4	10	0.5	27.5	32.5	39.5
Colorado		1			0	90	0	10
Florida	1				25	25	25	25
Georgia				2	0	2.5	10	87.5
Idaho		1			30	0	0	70
Illinois				2	0	2.5	2.5	95
Indiana		1	1		0	0	25	75
Iowa			1		0	0	0	100
Kansas				1	0	0	20	80
Kentucky		2		1	16.7	41.7	25	16.7
Louisiana		1			0	0	5	95
Michigan			1		0	100	0	0
Minnesota			1		0	10	50	40
Montana		1			95	5	0	0
Nebraska		1			100	0	0	0
Nevada				1	0	0	0	100
New Jersey		1		1	12.5	27.5	22.5	37.5
New Mexico		1		1	22.5	67.5	7.5	2.5
New York				1	0	0	0	100
North Carolina				1	0	30	10	60
North Dakota		1			25	25	25	25
Ohio			1		0	0	0	100
Oklahoma				1	0	20	0	80
Oregon	1	1			5	20	60	15

State	In your state, how often are existing highway structures inspected for bats by DOT staff, consultants, or academic biologists? NOTE: EACH RECIPIENT COULD CHOOSE ONE OPTION				What happens when bats are found during a project? Please provide an approximate percentage of the time a particular scenario applies. NOTE: EACH RECIPIENT COULD APPLY A PERCENT OCCURRENCE RESPONSE TO EACH OF ONE OR MORE CATEGORIES			
	I am unaware of any such inspections	Irregularly and unplanned	Part of our routine inspection/maintenance program	Structures are routinely checked before any repairs or removals	Move forward with the project without regard to the bats	Wait for bats to leave for the season (seasonal avoidance) and proceed with construction or building the bats out (i.e., exclusion)	Move forward with the project after ensuring the bats are protected	Obtain data about the type of bats that are present and consult with natural resource agencies
Pennsylvania		1			0	0	0	100
South Carolina	1				0	50	0	50
Tennessee	1				0	15	0	85
Texas				1	10	65	25	0
Vermont				1	0	75	25	0
Virginia			1		0	34	33	33
Wisconsin				1	0	25	25	50
Wyoming		1			0	90	0	10
Total	5	19	12	26	10	28	14	48

Figure 2. Responses to how often highway structures are inspected for bats



before implementing measures ensuring bat protection. Projects moving forward without regard for bats occurred least frequently (10% of the time).

1. **Which of these best describes the relationship between bats and highway structures (primarily bridges and culverts) in your state?**

Most (33 cases) participants indicated their respective states neither encourage nor discourage bats from using structures so long as the bats do not represent a safety hazard. In 25 cases, respondents indicated that while they do not seek to attract bats, efforts are made to protect any bats found. Two states (Oregon and Texas) are actively attempting to attract bats and no states are attempting to discourage bats from using highway infrastructure, although it's notable that during follow-up surveys, one state (Nevada) indicated efforts to attract bats were abandoned following a negative experience with an attempted exclusion.

2. **Is your agency/organization involved in efforts to attract bats to free-standing artificial roosts by using bat boxes, artificial bark, rocket boxes, or other such approaches?**

Twenty-seven participants indicated involvement in efforts to attract bats to free-standing artificial roosts (e.g., bat boxes, artificial bark, rocket boxes, or other such approaches). Participants could choose more than one option. A summary explaining efforts to attract bats follows:

- We occasionally work with third parties to allow them to install bat roosts on properties under our control (such as scout projects installing boxes at rest areas), but do none ourselves: 7
- We occasionally include bat boxes as part of a larger mitigation suite: 24
- We regularly install artificial roosts: 4

2.0 Step 2. Develop an understanding of how bats use highway infrastructure in your area.

This section is designed to identify instances where highway infrastructure is used by bats.

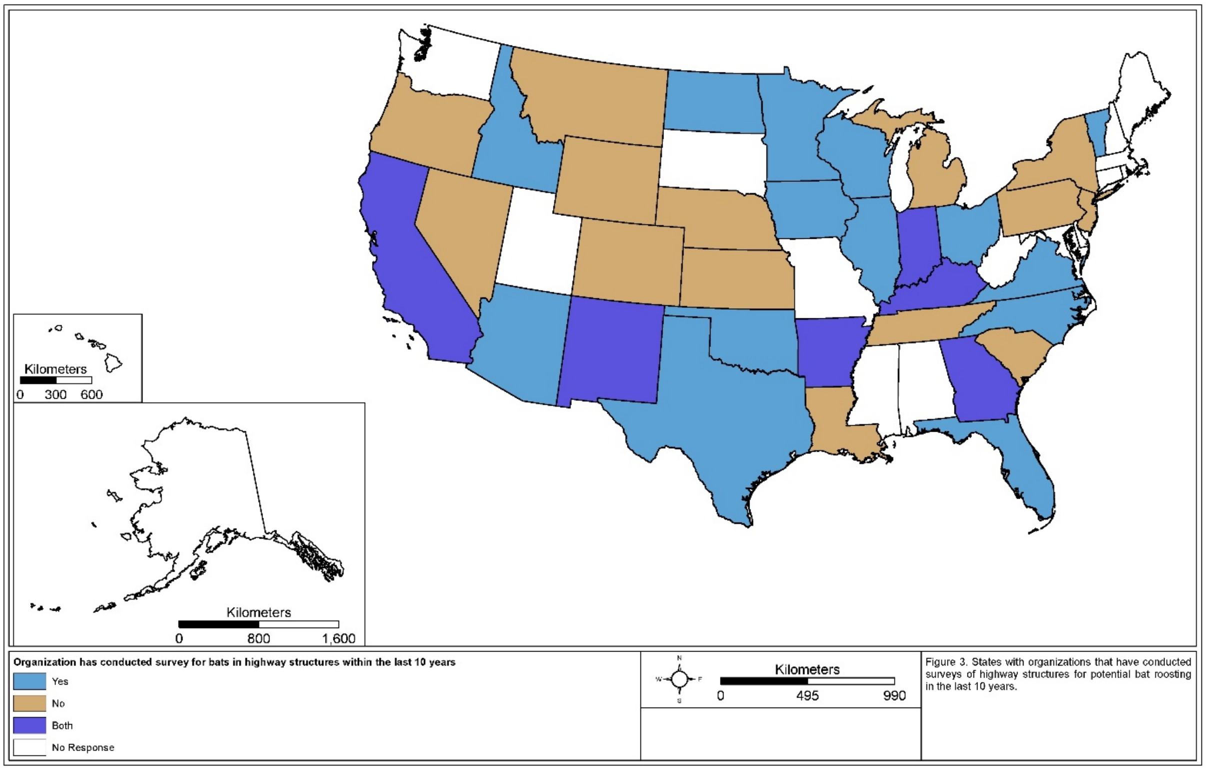
3. Has your organization conducted a survey of roadway bridges and structures for potential bat roosting in the last 10 years?

Sixty-one participants responded: 30 indicated no surveys of roadways and bridges were conducted in the past 10 years; 31 indicated surveys of roadways and bridges were conducted in the past 10 years. There is little spatial pattern related to states where surveys were conducted in the last 10 years, with few states in the northwestern quarter of the contiguous U.S. having conducted surveys (Figure 3). For states where both positive and negative responses were given, it is likely respondents were from different organizations. For example, in the cases of Indiana, Kentucky, and Arkansas, surveys were performed by academic scientists, but not transportation biologists. Twenty-four participants expressed an interest in sharing pertinent information.

- Arizona
- Arkansas
- California (multiple)
- Georgia
- Illinois
- Indiana
- Iowa
- Kentucky (multiple)
- Minnesota
- North Dakota
- Ohio

- Oregon
- Texas
- Vermont
- Wisconsin

Figure 3. States with organizations that have conducted surveys of highway structures for potential bat roosting in the last 10 years



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4. **Within your area, are you aware of colonies of bats in bridges or culverts?**

Of 62 participants, 12 were unaware of bat colonies in their areas and 49 were aware of bat colonies in bridges or culverts within their areas. Nineteen respondents indicated willingness to share data and 13 provided contact information:

- Arizona
- Arkansas (multiple)
- Georgia
- Indiana
- Kentucky
- Michigan
- Minnesota
- Nebraska
- Nevada
- Ohio
- Texas
- Vermont

Notably, an individual from Indiana did not complete the survey, but provided additional details to the survey team via electronic mail.

5. **How were those bats distributed (best guess) among bridges versus culverts (defined by Federal Highways Administration as being 20 feet (6.08 m) or less of road length).**

Bats were overwhelmingly (88% of the time) associated with bridges, while 12% were found in culverts.

6. **Do you have detailed information on the number and type of bat(s) present at the bridge(s)/culvert(s)?**

Thirteen respondents indicated they had detailed information on bats in bridges and one summarized data from Minnesota indicating all four cave-dwelling bats in the state also occupy highway bridges. Ten respondents offered to provide additional details and are listed below.

- Arizona
- Arkansas
- Georgia
- Indiana
- Minnesota

- New Jersey
- Ohio
- Texas
- Vermont
- Wisconsin

7. **Which method describes the most common method used to obtain information on the number of bats present at a site in your area?**

A variety of techniques are used to obtain information about the number of bats per location in a state, the most common responses included a crude estimate and emergence counts with 16 responses. More intense efforts such as direct nose counts (4 responses) and density-based estimates (2 responses) were less common. Six states provided additional detail as follows:

- California: Determines general abundance instead of direct counts with emergence counts, guano searches, thermal imaging cameras, and acoustic detection. Methods used are project-dependent.
- Florida: Different projects use different methods. During culvert surveys there is a direct count of bats. Bridge surveys by volunteers mostly provide simple presence/absence data. Some bridge surveys by biologists have been conducted in the past but I am unaware of their exact methods.
- Georgia: The chosen method is dependent on the structure (i.e., how accessible the structure is and where the bats are located, etc.). Most of the time, our ecologists survey bridges and note if any are found/the number of bats present/and species. If a large roost is observed, we work with our agencies to assist in determining the number/species (usually using the method of estimating the density multiplied by area occupied). If a structure is too large, we complete emergence counts.
- Nevada: Have used direct count when only a few are observed and use estimate of density and emergence count with larger colonies.
- Ohio: Identifies species with eDNA (environmental DNA likely from guano).
- Oregon: Usually the only bat information we obtain is when bridge inspectors note bat presence on their inspection sheets during an inspection.
- Texas: In most instances Texas DOT estimates are best guess by the observer. However, Texas DOT conducted a multi-year study of the bats under the Salado and Lampasas bridges over I-35 prior to their removal. Both bridges provided major bat roosts; bats were pit tagged, bridges were marked and nose counts were conducted over several months; habitat volume was calculated along with relative humidity and other measurements; artificial bat boxes were designed to replace the amount of habitat taken when bridges were removed and were placed on new bridges;

monitoring to determine success revealed that in 2018 all artificial bat boxes on both bridges were fully occupied.

8. Which best describes who estimated the numbers of bats present in your area?

When estimates are completed they are typically completed (32 cases) by trained observers. However, some states used untrained observers (8 cases). Six states provided more detailed responses:

- Arizona: Single observation by trained observer used for discrete roosting locations like bridges and culverts; in another area where bats were roosting in cracks in rock, multiple observations by trained observers were used to estimate the number of bats using different areas of the landscape.
- California: If signs of bat use are detected during day surveys, such as guano, urine or other indicators and there is habitat on the bridge that may be suitable for day or maternal roosting, or used as a hibernaculum (for cave-analog bats), at least one dusk/night visit for surveys is conducted with at least 1 experienced biologist on a team of 3-4 biologists. Observers examine most likely habitat areas where bats may leave structure and also conduct Sonobat® (a brand of acoustic bat detectors) surveys to try and determine what bat species might be present. For larger projects where removal of old buildings may be involved, a bat-specialist contractor is hired to complete detailed surveys which may include habitat inspection, habitat exit surveys, mist net surveys and Sonobat® surveys.
- Georgia: GDOT ecologists, as well as consultants working on GDOT projects, have taken a training session on Bats in Bridges provided by the GADNR to help train ecologists on what to look for when inspecting bridges and culverts. We also regularly meet GADNR and USFWS in the field at structures with large roosts. Typically, if there is a large roost, the site is visited multiple times with GDOT staff as well as agency representatives.
- New Mexico: Use an environmental consultant that specializes in bats within southwest region.
- Oregon: There usually is no attempt to estimate bat numbers. (It should be noted that this is the case because Oregon has no federal or state Endangered Species Act (ESA) listed bats so there is no mandate to survey).
- Vermont: Greatly varies, surveys are done throughout the state by several parties.

9. How is information about the type of bats present typically obtained in your area?

As with efforts to count bats, efforts to identify bats are made by experienced biologists (25 responses) in most cases. Four participants said they attempt identifications using only field notes and limited training, one participant responded that identification is made using a “most likely species approach”, and three participants said they use all three methods (experienced biologist, limited experience, “most likely species” approach). Three participants said they send photos to bat biologists for identification. Two participants said they typically do not attempt identifications. Several detailed responses follow:

- California: More than one technique is used depending on species presence and magnitude of project. For projects where there is minimal potential for bat presence or bat impacts such as a maintenance project that will only involve performing work on the upper deck of a bridge, identification is based on a 'most likely species' approach using a statewide database and known ranges of various species and known preferred habitat of various species. For major bridge projects (e.g., replacement or expansion), visual observation, consultation with local specialists such as California Dept. of Fish and Wildlife or U.S. Forest Service biologists and Sonobat® data are used. For projects with likely presence of species of special concern such as pallid bat or Townsend's big-eared bats, an experienced bat biologist consultant may also be employed if day roost or maternal habitat is believed present.
- Nebraska: NDOT (Nebraska) stated they surveyed bridges in state and found very few with bat use. I am a bat biologist at a University and find bat use under most bridges in the state near water and trees! Potentially a disconnect with having inexperienced people survey bridges. Most bridges are used as night roosts and not many day roosting bats.
- New Jersey: Acoustic recordings during emergence surveys, and/or ID made by experienced biologists if roosting bats are readily visible (tele-photography also used).
- New Mexico: Identification is performed by experienced bat biologists and inexperienced individuals. Often surveyors with limited experience use field guides to identify bats. If the surveyor is still uncertain about the type of bat, he/she can reach out to experts for help.

10. Within your area are you aware of colonies of bats in free-standing artificial roosts (e.g., bat boxes, artificial bark, etc.)?

Twenty-two participants were aware of colonies of bats in free-standing artificial roosts within their areas: Five provided numbers of bats using roosts and nine provided contact information.

- Indiana:
  - How many roosts contain bats?: 171
  - How many did not contain bats when checked?: 2270
- Montana:
  - How many roosts contain bats?: 50%
  - How many did not contain bats when checked?: 50%
- New Jersey:
  - How many roosts contain bats?: 40
  - How many did not contain bats when checked?: 65
- Texas:
  - How many roosts contain bats?: 14
  - How many did not contain bats when checked?: 12
- Wisconsin:
  - How many roosts contain bats?: ~150
  - How many did not contain bats when checked?: ~15

11. Do you have information on the number and type of bat(s) present at the roost(s)?

Six of 14 participants had information on number and type of bat(s) present at the roost(s) and were willing to provide information.

- Indiana
- New Jersey
- Ohio
- Wisconsin
- New York
- Vermont

12. Which method describes the most common method used to obtain information on the number of bats present at a site in your area?

All 20 participants that were aware of colonies of bats in free-standing artificial roosts within their areas provided responses: ten reported the use of emergence counts to obtain information, three used crude estimates, and one reported a direct count of roosting bats or use of photography to "count noses." Three states provided additional details:

- Arkansas: Respondent indicated attempts were made to get homeowners to conduct emergence counts at occupied bat houses, but almost no participation occurred.
- New York: Photography is used in winter; emergence counts are used in summer;
- Texas: During the Texas DOT study of the Lampasas and Salado bridges bats, mark recapture was used to estimate bat use of artificial boxes. Bats were pit tagged over several years and a pit tag reader was installed on one of the artificial boxes. Prior to deconstructing the bridges photography and nose counts were used to estimate bat usage of these two bridge structures. Usually estimates of numbers would be crude estimates of the observer.

13. Which best describes who estimated the numbers of bats present in your area?

Most estimates were based on multiple observations by trained observers, one participant reported bat populations were estimated using a single observation by untrained observer(s).

14. How is information about the type of bats present typically obtained in your area?

Bats were typically identified by experienced bat biologists (16 cases), although identification based on field guides and limited experience was reported by four respondents.

3.0 Step 3. Bat mitigation options pursued in this area.

The goal of this section includes gathering information about the types of mitigation in use in an area.

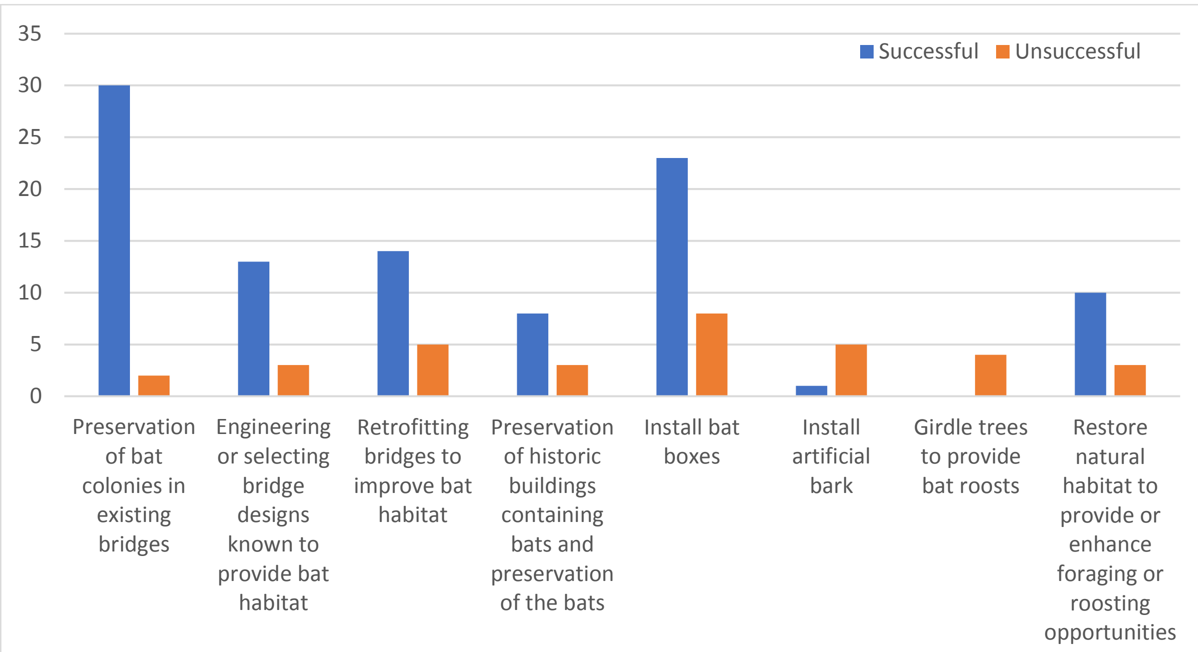
15. What is/are the reason(s) bat mitigation is being pursued:

When asked to rank reasons for pursuing bat mitigation, respondents indicated compliance with the federal ESA as the primary reason (average rank 1.7, where a score of 1.0 indicates this was the highest concern for all recipients) for implementing mitigation measures. The other options did not vary enough to be confidently ranked: Good environmental stewardship or public relations (average rank 2.9), Compliance with state-level rare species laws (average rank 2.8), and minimizing impacts to the environment as part of compliance with the National Environmental Policy Act (NEPA) (average rank 2.6).

16. Which of the following have been used in your region to provide habitat for bats? *Mark all that apply and indicate if they were successful (S) or unsuccessful (U)*.

Respondents indicated preservation of bat colonies in existing bridges was the most successful method for providing bat habitat, and that engineering bridges for bat use was not regularly attempted (Figure 4).

Figure 4. Successful and unsuccessful approaches to providing bat habitat.



Other mitigation approaches received mixed reviews and a summary of responses follows.

- Preservation of bat colonies in existing bridges:
  - Successful: 30
  - Unsuccessful: 2
- Engineering or selecting bridge designs known to provide bat habitat:
  - Successful: 13
  - Unsuccessful: 3
- Retrofitting bridges to improve bat habitat:

  - Successful: 14
  - Unsuccessful: 5
- Preservation of historic buildings containing bats and preservation of the bats:
  - Successful: 8
  - Unsuccessful: 3
- Install bat boxes:
  - Successful: 23
  - Unsuccessful: 8
- Install artificial bark:
  - Successful: 1
  - Unsuccessful: 5
- Girdle trees to provide bat roosts:
  - Successful: 0
  - Unsuccessful: 4
- Restore natural habitat to provide or enhance foraging or roosting opportunities:
  - Successful: 10
  - Unsuccessful: 3

17. How does your organization define a success? Choose ONE from the following:

Respondents provided a range of responses to this question as summarized below.

- Mitigation is considered a success when it is installed or available to the bats: 13 respondents
- Mitigation is considered a success if it leads a project to permit approval: 12 respondents
- Mitigation is considered a success when it is used by bats regardless of the number or species: 24 respondents
- Mitigation is considered a success when it is used by a targeted number of bats. Please indicate a typical target number __________: 3 respondents
  - Two participants said mitigation was a success when numbers were back to pre-disturbance levels
  - One participant said numbers needed to be at least 25 percent of pre-disturbance numbers

- Mitigation is considered a success when it is used by a specific prioritized species: 6 respondents
- The success of mitigation scales to the "biological value" of the use such that presence of a few common bats is good, but attracting a maternity colony of rare bats would be even better: 7 respondents
- Other: 8 respondents (see below):
  - Illinois: The respondent said the state avoids impacts to bats;
  - California: No bat specific mitigation projects have been implemented in the San Francisco Bay Area, but some are in planning stages;
  - Colorado: There is only one project the respondent knew of that included bat mitigation. The respondent said that including mitigation on a project is difficult because there are no federally listed bats in Colorado;
  - Georgia: Their typical mitigation process is using bat in-lieu fee. For structures where found maternity colonies are found, they work with their state and federal agencies to ensure limited harm is done to the maternity colony (i.e., limiting work during the active bat season, having bat biologists present during maintenance/construction of bridges to ensure bats are not being harmed, etc.). GDOT considers a project a success when an existing maternity colony is unharmed by maintenance work (and that the proposed work to the structure is able to be completed);
  - Nevada: Mitigation is a success if they are able to complete their project with no impact to the bats. Normally this means avoidance of work area while bats are present, typically requiring late fall and winter work;
  - Ohio: meets criteria of established agreement (in reference to a Biological Opinion and Incidental Take Statement issued by the U.S. Fish and Wildlife Service [USFWS]);
  - Oklahoma: Because they have few bridges with bats, mitigation is rare. The respondent was aware of less than three mitigation efforts. Usually, they just avoid the active or pup season as required according to the species listed for that project; and
  - Pennsylvania: In the past, they pursued mitigation by payment to an in-lieu fee fund specific to Pennsylvania and allow the Pennsylvania Game Commission and USFWS to use funds on their behalf for conservation of the federal and state listed species, primarily federal species. They recommend contact with the USFWS Pennsylvania Field Office, Robert Anderson for additional information on this. Recently, USFWS approved commercial conservation bankers in Pennsylvania and began purchasing credits from these entities rather than payment to the fund;

18. Do you cooperate on bat mitigation with a person(s) from another organization.

Of 52 participants who responded to this question, 19 did not cooperate on bat mitigation with person(s) from another organization and 33 cooperated on bat mitigation with person(s) from another organization. Follow-up questions for those 33 who indicated cooperators were most often biologists/regulators employed by a natural resource or wildlife agency (27 responses), although consultants (5 responses), outside biologists (6 responses), other transportation professionals (3 responses), and academic scientists (3 responses) were also included. Multiple response options were allowed for selection.

19. Does that organization use a different definition of success?

Only 9 of 33 respondents who cooperate with an outside agency indicated the agencies had differing definitions of success. Five responded mitigation is considered a success when used by bats regardless of the number or species, three responded mitigation success scales to the "biological value" of the use, one responded mitigation is considered a success when installed or available to bats, and two responded mitigation is considered a success when used by a specific prioritized species.

20. Do you have information about how much the mitigation costs in time or dollars?

Eighteen participants replied that they had information about how much the mitigation costs in time or dollars.

- Arizona
- Arkansas
- California (multiple)
- Indiana
- Iowa
- Kentucky
- Ohio
- Texas
- Vermont
- Wisconsin

21. Was there monitoring associated with the structures used for mitigation?

Twenty-five of 46 participants responded that monitoring was completed on structures used for mitigation. Thus, in about 46 percent of cases (21 of 46 responses), no monitoring was required. The frequency with which structures were monitored varied among a regular monitoring schedule (13 responses), annual checks (7 responses), periodic monitoring based on convenience (8 responses), and more than once a year (7 responses).

22. Was a goal of the monitoring to identify maintenance/repair needs?

Of 26 participants that replied, only four indicated a goal of monitoring included identifying maintenance/repair needs. One responded roosts were repaired as needed, one responded that roost repairs were either planned or repaired as needed, one responded that repairs were not needed, and one responded that damaged roosts were not repaired.

23. Were structures monitored to identify the type of bats present?

Of 43 participants that replied, 23 did not monitor structures to identify type of bats present. Twenty respondents monitored structures to identify type of bats present and generally recorded presence/absence (18 respondents), species (18 respondents), and type of use (13 respondents).

24. Was the goal of the mitigation to attract any specific type of bat?

Of 41 participants that replied, 34 indicated the goal was simply providing bat habitat regardless of species using the habitat. In Indiana, the goal was protection of the Indiana bat, whereas Ohio indicated a mix of targeting common species and rare species, especially the Indiana, northern long-eared, and little brown bats. Respondents from California focused on crevice-roosting species as opposed to cave roosting species and an existing Yuma myotis (*M. yumanensis*) maternity colony roosting in a bridge.

4.0 Step 4. Looking toward the future.

25. In the following boxes please indicate your opinion about any expected changes in the way bat roost mitigation will be implemented in the future, and why do you expect these changes.

These open-ended questions, as intended, generated a variety of responses including:

- Statements about how mitigation approaches and regulatory mechanisms could be expanded or changed to better address presence of bats associated with highway infrastructure including;
    - lessons learned by one or more DOTs,
    - application of new information provided by researchers,
- Statements that improving science or improved communication between researchers/natural resource agencies and DOTs would lead to an increased focus on bats and highways or more successful ways of mitigating impacts on bats;

    - Including the ability to apply lessons learned by one or more DOTs, and
    - application of new information provided by researchers,
- Statements noting the relationships between future mitigation policies and future financial and regulatory requirements faced by the DOTs and their partners including;
    - Potential that bats would be an area of increased focus resulting from population declines due to WNS and the potential that more bats will be added to state and federal rare species lists,
    - An expectation that a growing public awareness about bats would create a greater focus on bat conservation, and
    - Statements that the status quo would be maintained unless there were changes to regulatory or funding requirements,
- One statement about the use of environmental DNA to verify the species of bats present under bridges.

What information if any would help you address these future changes?

- Arizona: Information on effective exclusion methods used by other DOTs for excluding bats from cracks in bridges and rocks, etc.
- California: What potential replacement habitat is there for cave-analog bats such as the Townsend's big-eared bat?
- California: Shared knowledge from regional and national mitigation successes. A regional standardized approach to measuring success would be beneficial, but managers need to understand that no two projects are the same and there can be no “standard” mitigation technique.
- Colorado: Information on the types of bridges, or features of bridges that could be included in design, would make it easier for their biologists to suggest including them in plan sets.
- Georgia: The success of other DOTs using artificial roosts, whether they added an artificial roost to the existing structure, designed new bridges/culverts in a way that provided artificial roosts without inhibiting future maintenance work, or added artificial roosts near bridges/culverts. It would also be interesting to see if artificial roosts are ever added to edges of forested habitat after tree clearing has occurred as a way of mitigating habitat loss. If other DOTs are using these artificial roosts, data on how it helped with decreasing time needed with agency consultation/streamlined project delivery would be beneficial when trying to implement using artificial roosts with GDOT work.
- Idaho: Funding for bat surveys on our facilities.
- Indiana: Cost-benefit analysis that focuses on the definition of success.

- Kentucky: A recent paper from the Iowa DOT provides an excellent example of the type of data needed (Bektas et al. 2018).
- Minnesota: BMPs for maintaining and creating bat habitat within a transportation system.
- Nebraska: Application of lessons learned in other states.
- Nevada: If there was some form of a reward system for environmentally friendly designs, I think that could be an incentive to integrate bat friendly designs. Right now, bats on bridges create such a headache for repairs, that bat friendly designs are proving impossible to encourage. The answer the respondent has received is: “Why would we want to encourage bats if we cannot repair the bridge once bats are established?” It has become very counterproductive.
- New Jersey: There's some good guidance out there, but more info about the percentage of bridges (of various types) used by bats (of various species) in the northeastern U.S., and success of various mitigation strategies would be helpful.
- New Mexico: A better understanding of seasonal bridge use by bats prior to repairs, improvements or reconstruction of bridges.
- North Dakota: It would be great if state DOTs that have been active in bat mitigation for many years, share information with other states as more species are on the radar for listing under the ESA. Northern states face more challenges because we have a very short construction season, which happens to coincide with our active bat season. Mitigation is therefore difficult to implement when dealing with a short construction season.
- Oregon: Designs for "artificial caves" that bats will use that can be attached to bridges regardless of the bridge type would be great. Bats regularly use box bridges, but box bridges often aren't the preferred design for new bridges.
- Tennessee: Programmatic agreements between USFWS and FHWA.
- Texas: Documentation of the economic value of bats occupying transportation structure. Any information that demonstrates the positive aspect of having bats occupy infrastructure. Guidance from AASHTO to incorporate into design manuals bat friendly bridge design options.
- Vermont: Types of roost designs that are the most effective.

5.0 Literature Cited

Bektas, B. A., Z. Hans, B. Phares, E. Nketah, J. Carey, M. K. Solberg, and K. McPeek. 2018. Most likely bridges as roosting habitat for bats: Study for Iowa. Transportation Research Record:1-10.