Assessing Bridge Characteristics for Use and Importance as Roosting Habitats for Bats

Final Report
November 2018

BRIDGE ENGINEERING CENTER

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Institute for Transportation

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Iowa Department of Transportation (InTrans Project 15-505)

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16. Abstract

Bats play an important role in the natural balance of many ecosystems. As a result, there has been a growing concern about the number and status of bats in the US and beyond. Concern over bat populations is primarily driven by the fact that habitats used by bats for roosting and foraging have been disturbed, altered, or reduced. In Iowa, at least one federal endangered bat is known to exist and thought to be potentially impacted by habitat influences.

Conservation efforts targeted toward bats can be hampered by a lack of information on their habitats and usage. Although it is widely accepted that bats use bridges as roosting sites, little attention has been given to understanding the combined bridge and location characteristics associated with their use of bridges as roosting sites. Therefore, it is important to investigate how, why, and when bats use bridges as roosting sites.

A major goal for this study was to better understand when bridge replacement/repair/ rehabilitation projects have the potential for "taking" (i.e., harassing, injuring, or killing) bat species that have been identified as federally threatened or endangered bat species. The primary objective of this work was to better understand what type of bridges (based on bridge characteristics including local topography and habitat availability) are the most likely to be used by bats as roosting locations. The study also aimed to document the means and methods developed and followed to conduct this work so that the evaluation protocol can be used by other states/regions.

The findings showed that bridge characteristics, combined with land cover and bat species distribution data, can help identify locations with higher probabilities of bat roosting. This information can be useful to transportation agencies as they plan bridge replacement/repair/rehabilitation projects and can help conservation efforts targeted toward bats.

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ACKNOWLEDGMENTS

The research team would like to acknowledge the Iowa Department of Transportation (DOT) for sponsoring this research and the Federal Highway Administration (FHWA) for Surface Transportation Program (STP) funds used for this project. The research team would also like to thank the project panel for their valuable input throughout the project.

EXECUTIVE SUMMARY

Problem Statement

Although it is widely accepted that bats use bridges as roosting sites, little attention has been given to understanding the bridge, bat distribution, and location characteristics associated with use of bridges as roosting sites. Therefore, it is important to investigate how, why, and when bats use bridges as roosting sites.

Goal and Objectives

The major goal for this study was to better understand when bridge replacement, repair, and rehabilitation projects have the potential for "taking" (i.e., harassing, injuring, or killing) federally threatened or endangered bat species.

To achieve that goal, the project had the following objectives:

- Better understand what type of bridges, based on bridge characteristics including local topography and habitat availability, are the most likely to be used by bats as roosting locations
- Document the methods developed and followed in this study so that the evaluation protocol can be exported to other states and regions

Background

There has been growing concern about the bat population in the US, mainly due to the outbreaks of White-Nose Syndrome (WNS) and collisions with wind turbine blades. Concerns over the declines in the bat population are also driven by the fact that habitats used by bats for roosting and foraging have been disturbed, altered, or reduced.

Bat conservation efforts have been hampered by a lack of information on how to provide suitable environments, especially at critical roosting times (e.g., maternal roosting). Further complicating the situation is that some locations may be used only for brief time durations and sometimes for specific usages (hibernation, maternity, etc.).

In Iowa, at least one federally endangered bat (the Indiana bat) is known to exist and thought to be potentially impacted by habitat influences.

Project Description

The research team established the general types of land cover characteristics and structure characteristics that bats generally prefer and where those types of bridges exist in Iowa through a literature review and data provided by sources such as the National Gap Analysis Program, National Bridge Inventory, and data collected during field inspections.

The research team randomly sampled and inspected 517 structures as part of the study. The field inspection process took place during the summer of 2016, where trained teams acquired detailed evidence of bat roosting at bridges.

The evidence could include bat droppings, visual sightings of flying bats, or presence of roosting bats. The teams also collected other data such as roost type, roost dimensions, conditions surrounding the roost, and surrounding habitat. Items supplementing each inspected bridge structure included photographic and documented indications of the existence or inexistence of bats.

Once all the data were collected, the team used logistic regression models to estimate the probability of bat presence based on bridge characteristics, potential bat presence, land cover, and field-collected data items.

Key Findings

The final model indicated the probability of bat roosting on bridges increased significantly when structures met the following conditions:

- Prestressed concrete continuous, prestressed concrete, or steel continuous
- Increased superstructure height above ground
- Increased superstructure depth
- Increased wetland coverage within 0.1 mile radius of the structure
- Increased number of potential bat species at the location

The findings showed that bridge characteristics, combined with land cover and bat species distribution data, can help identify locations with higher probabilities of bat roosting.

To the authors' knowledge, the integration of objective graphic information system-based (GIS-based) land cover data with potential bat presence data, and estimation of quantitative and relative influence of variables on probability of bat roosting are unique to this study.

Implementation Readiness and Benefits

The results of this work can be useful to transportation agencies as they plan bridge replacement, repair, and rehabilitation projects and can help conservation efforts targeted toward bats. The findings provided the Iowa Department of Transportation with the ability to proactively identify locations with a high likelihood of bat roosting.

In addition, the study can be adapted and performed by any other state or agency. To aid in the effort, the project team put together an instructional video on inspections for bat roosting at bridges. The video can be accessed at this link.

Recommendations

- It is important to have an interdisciplinary project panel that can provide input to the researchers throughout their studies.
- It is critical to have a random sample of bridges for inspections, in order to have an unbiased sample that can be later used in statistical analysis. Researchers may add other variables that are relevant to their locations to this list.
- Researchers may use other statistical models or analyses based on the findings they are interested in, or may add other questions of interest.

INTRODUCTION

Bats play an important role in the natural balance of many ecosystems. There has been growing concern about the bat population in the US, mainly due to the outbreaks of White-Nose Syndrome (WNS). WNS was identified in New York in 2006, and is estimated to have killed more than 5.7 million bats in eastern North America since then (Gilles 2017*)*. Current research suggests that bat fatalities are also caused by collisions with wind turbine blades. It was reported that at some sites in the Midwest and eastern US, species already battered by WNS account for up to 60 percent of wind-energy fatalities (Bat Conservation International Inc. n.d.). Concern over the declines in bat population is also driven by the fact that habitats used by bats for roosting and foraging have been disturbed, altered, or reduced. In Iowa, at least one federal endangered bat (Indiana bat) is known to exist and thought to be potentially impacted by habitat influences.

Conservation efforts targeted toward bats can be hampered by lack of information on their habitats and usage. As a result, many questions may go unanswered as to how to provide suitable environments–especially at critical roosting times (e.g., maternal roosting). Fortunately, many bat species are able to adapt to a variety of roosting locations that can include natural "structures" (e.g., caves, trees, rocks, etc.) and manmade structures (e.g., bridges, buildings, etc.). Further complicating the situation is that some locations may be used only for brief time durations and sometimes for specific usages (hibernation, maternity, etc.). Although it is widely accepted that bats use bridges as roosting sites, little attention has been given to understanding the characteristics associated with their use as day, night, or maternal roosting sites. Therefore, it is important to investigate how, why, and when bats use bridges as roosting sites.

A major goal for this study was to better understand when bridge replacement/repair/ rehabilitation projects have the potential for "taking" (i.e., harassing, injuring, or killing) bat species that have been identified as federally threatened or endangered. The primary objective of this work was to better understand what type of bridges (based on bridge characteristics including local topography and habitat availability) are the most likely to be used by bats as roosting locations. The secondary objective of this work was to document the means and methods developed and followed to conduct this work so the evaluation protocol can be exported to other states/regions. The objectives were achieved by:

- Establishing the general types of landscape characteristics and "structure" characteristics bats generally prefer based on the literature review
- Identifying, using geographic information system (GIS) data, bridges in Iowa that are in bat-friendly landscapes
- Conducting field surveys of selected bridges to identify:
    - Evidence of bats using the bridges as roosting locations
    - Structural characteristics of all bridges in the study sample
- Analysis of collected information to identify structural/environmental conditions that are most likely to attract roosting bats
- Documentation on process and procedures for determining bridge likelihood as a bat roosting habitat.

LITERATURE REVIEW

Bridges provide shelter and protection to bats and serve as different roosting sites; findings on bats' use of bridges as roosting habitat have been presented in the literature *(*Benedict and Howell 2008, Carden et al. 2010, Cleveland and Jackson 2013, Erickson et al. 2003, Feldhamer et al. 2003, Gore and Studenroth 2005, Hendricks et al. 2005, Keeley 2007, Keeley and Tuttle 1999, Perlmeter 1995, Shiel 1999, Smith and Stevenson 2013, Timpone et al 2010, Civjan 2017).

The studies vary in terms of coverage (national, statewide, or structure-specific) and study focus (bridge characteristics, monitoring techniques, bat types). While some studies looked into the impact of a particular factor on roosting (Smith and Stevenson 2013), others focused on field studies that tried to identify the bridge characteristics that made bridges more likely to be a roosting location for bats (Cleveland and Jackson 2013, Feldhamer et al. 2003, Gore and Studenroth 2005, Hendricks et al. 2005, Keely and Tuttle 1999). The latter group of studies that investigated bridge characteristics as they related to bat roosting on bridges is summarized in Table 1. Major findings from these studies are also summarized in this section.

Table 1. Studies related to bridge characteristics and bat roosting

Study	Variables considered	Significant/Influential variables
Keeley and Tuttle (1999)	Structure Type, Crevice Width and Depth, Roost Height, Traffic	Structure Type, Crevice Width and Depth, Roost Height, Traffic
Feldhamer et al. (2003)	Structure Type, Land cover	Structure Type
Gore and Studenroth (2005)	Structure Type, Age, Length, Height, Traffic	Structure Type*, Age, Traffic*
Hendricks et al. (2005)	Structure Type, Riparian Corridors, Land cover	Structure Type, Riparian Corridors, Land cover
Cleveland and Jackson (2013)	Structure Type, Riparian Corridors, Land cover, Crevice Type	Structure Type, Riparian Corridors, Land cover, Crevice Type

*Statistical significance was reported.

The research by Keeley and Tuttle (1999) has been the most comprehensive and cited study on bat roosting in American bridges. They surveyed 2,421 bridges in 25 southern and western states for bat roosting data. Bats were found in 211 structures (8.7 percent). Ideal bridge characteristics for crevice-dwelling bat species (in descending priority) were reported as:

- being located in relatively warm areas (primarily in southern half of the US)
- having concrete as construction material
- having vertical crevices of 0.5 to 1.25 in. in width
- having vertical crevices of 12 in. or greater in depth
- having roost height of 10 ft or more above the ground
- being rain sealed at the top
- having full sun exposure

- not being situated over busy roadways

In a Florida study, bats were found in 16 (5.4 percent) of the 299 randomly visited bridges (Gore and Studenroth 2005). Prestressed concrete bridges with multiple I-design beams, older bridges, and bridges with less average daily traffic were found more likely to be home to a bat.

In a Montana study, evidence of bat use was found at 78 of 130 highway structures examined (Hendricks et al. 2005). Roosts were found in all highway system categories, but relatively more were in the local/state-maintained category; maternity colonies occurred in all but the interstate category. Use of bridges for roosting, and intensity of use for night roosts, were generally unrelated to the landscape within 3 km (1.86 mi) of the structure. Only a mean percentage of forest cover was significantly greater around day roost structures, but substantial overlap among unused, night roost, and day roost categories indicated that this pattern was a trend and not the major influence on structure use by bats. All day roosts were found within 8 km. (5 mi.) of riparian corridors. Bats used 75.9 percent of concrete structures, 37.5 percent of steel structures, and 31.6 percent of wooden ones. Slab bridges were the least preferred concrete spans because they provided few if any protected sites for roosting bats on the underside of the deck.

Another study in Georgia (Cleveland and Jackson 2013) aimed to determine roost selection preferences of bats, specifically identifying those structures being utilized as bat roosts as well as the characteristics that made a bridge a suitable roost site. During a period from August 2003 through April 2005, 540 randomly selected bridges located in Georgia were surveyed. Within this sample, 55 bridges were identified as currently or previously occupied by roosting bats. The data from this study suggested that bats preferred to roost in bridges primarily constructed of concrete materials with open crevices. Roost bridges were most frequently surrounded by woodland/riparian habitat, though some were also found surrounded by residential dwellings, commercial areas, open farms, and ranch lands.

In nine southern Illinois counties, 232 bridges were surveyed for the presence of roosting bats, during July 2001, and June through August 2002 (Feldhamer 2003). Fifteen bridges (6.5 percent) had bats roosting at the time they were surveyed. Bat roosting occurred in four of the five types of bridge designs surveyed; flat slab bridges were never occupied by bats. No relationships between bat presence and habitat features around bridges could be determined.

In a recent study in New England, Civjan et al. (2017) monitored three regions, did rapid visual screenings of 191 bridges, and conducted a more detailed investigation of 18 selected bridges. The main objective of this study was to evaluate monitoring technologies including acoustic methods, infrared imaging, borescope inspection, and visual inspection. Fourteen bridges (five were monitored in this project and researchers were notified of nine sites by the state Department of Transportation) were positively identified as bat roosting sites through this project, with possible roosting at several other sites. This study focused on *M. Septentrionalis* and other nationally or regionally listed threatened species and developed a supplement to the FHWA/FRA Bridge/Structure Inspection Form (FHWA/FRA 2015).

The findings from the literature suggested that bats are more likely to use bridges as roosting habitat when the structures are concrete, typically girder structures that provide vertical crevices for shelter; near/on riparian corridors; on roads with low traffic volumes; and close to woodland.

RESEARCH APPROACH, DATA, AND ANALYSIS

Approach

As the initial step in the study, the research team did a comprehensive review of the national and international literature on bat roosting on bridges (Figure 1).

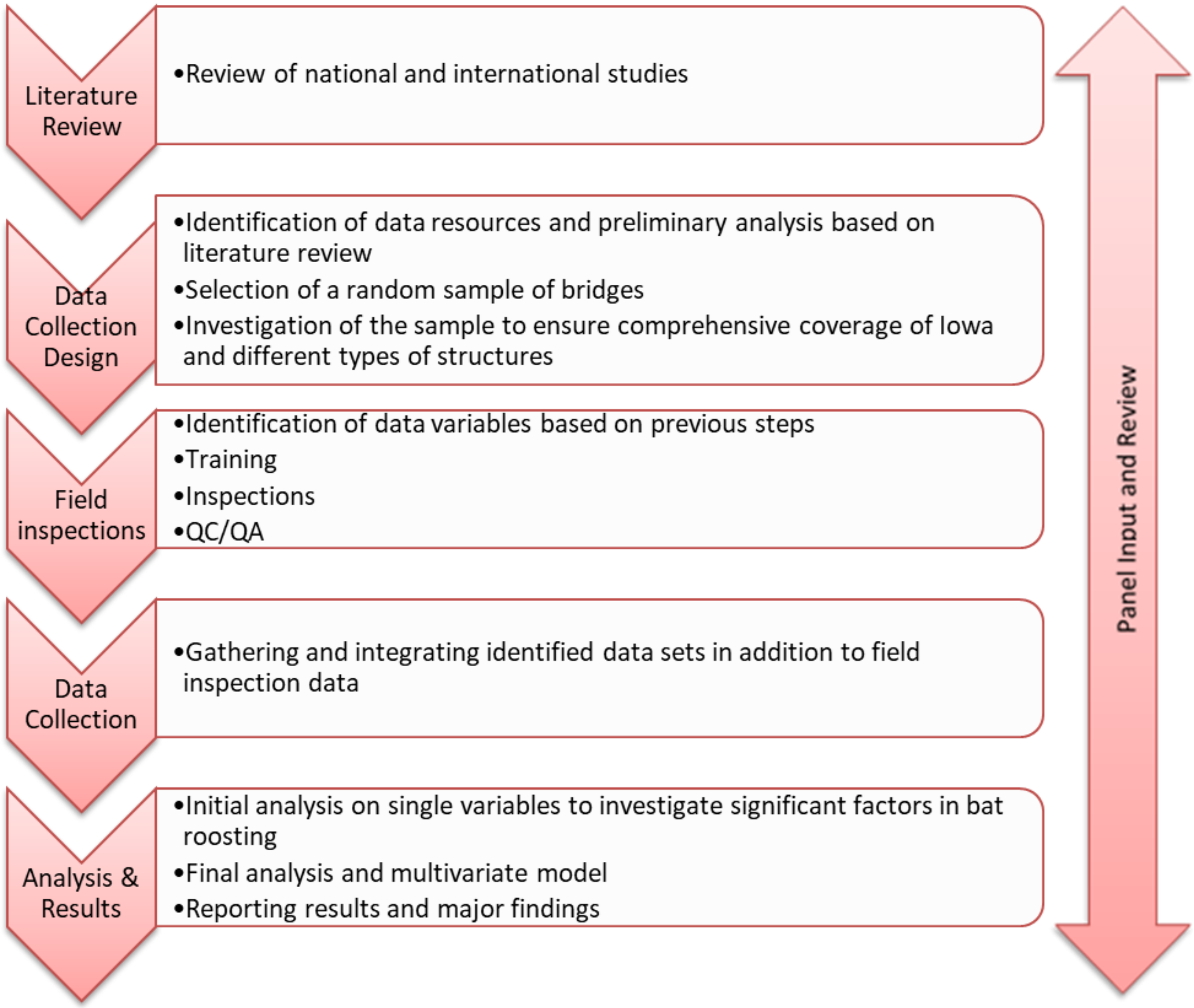

Figure 1. Study approach and steps

Earlier studies provided valuable findings and insights, which were incorporated into data collection design, inspections, and analysis. The team focused on integrating relevant data sources that were potentially associated with bat roosting. The study was also designed in a way that the team could ultimately do statistical analysis of the variables and quantify the likelihood of bat roosting for varying structures and conditions. The interdisciplinary project panel that included ecologists, environmental specialists, and engineers guided the effort throughout the project. The steps followed in the study are presented in Figure 1.

Data Sources

Primary sources of information for this investigation were comprised of data provided by: (1) the Iowa Department of Transportation (DOT) Geographic Information Management System (GIMS) database, (2) the Iowa Natural Resources Geographic Information System (GIS) Library, (3) the National Gap Analysis Program (GAP), and (4) National Bridge Inventory (NBI) (Figure 2).

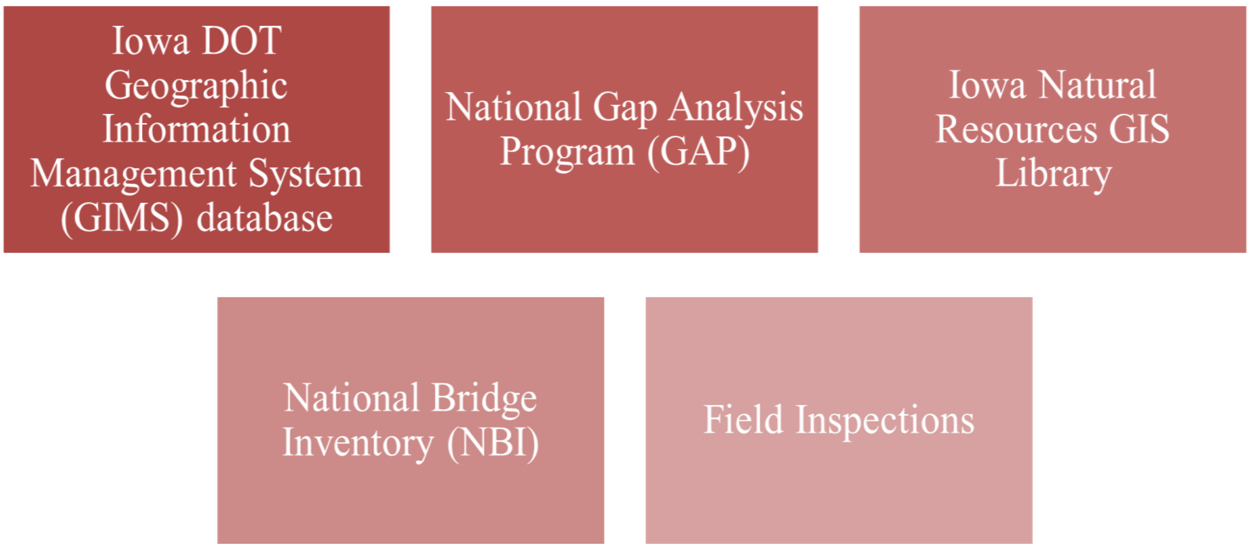

Figure 2. Study data sources

State-level inquiry and integration processes of all sources as of their most recent available data year were implemented using the ESRI ArcMap software program. In particular, from the GIMS database, Base Record Road and Structure information pertaining to all public roads in Iowa as of 2014 were of interest. To that end, surrounding land coverage and GAP-predicted bat species distribution or range were also attained for the most recent available year (2002). The structure data included the data items of interest among 116 NBI data items for all NBI structures in Iowa. However, for the purposes of this study, those structures serving railroads, or owned by other private organizations, were excluded, leaving 24,486 structures of interest.

Predicted distributions of bat species for Iowa were obtained from the Iowa Department of Natural Resources (DNR) Iowa Gap Analysis Program (IAGAP). Distributions were presented at a 30-meter spatial resolution, and were based on habitat models derived from IAGAP land cover data, hexagon range maps, survey data, and expert review. Similar data were also available nationally through the USGS National GAP (USGS n.d.a).

Predicted distributions for each bat species were spatially integrated with sample bridge locations, and the total number of possible species at each sample bridge was derived. Figure 3 shows coverages of some bat species found in Iowa.

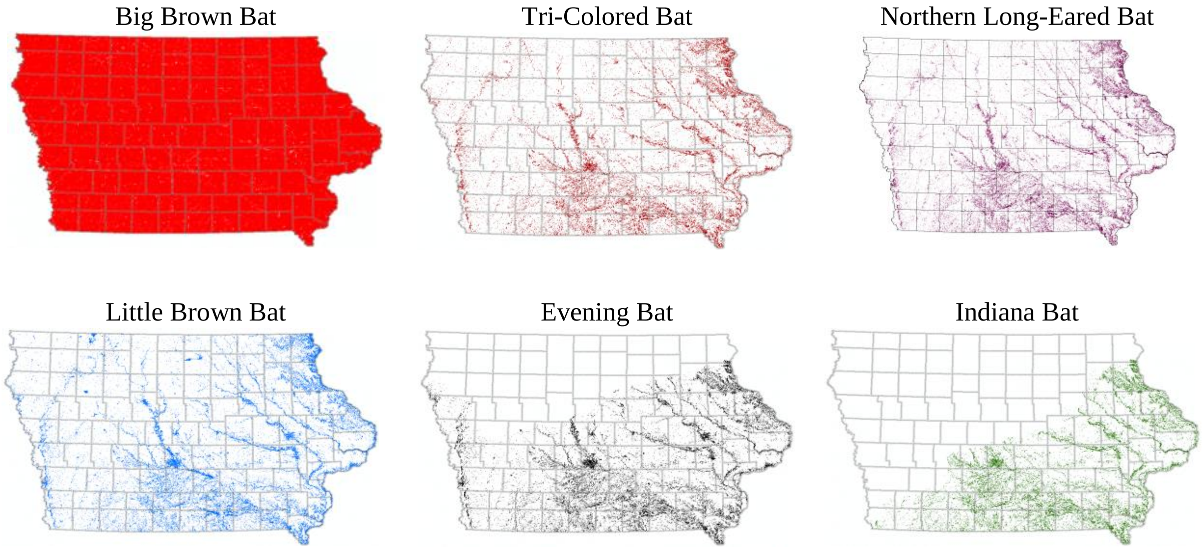

Figure 3. Screenshots of various bat species' coverage in Iowa

Ultimately, by use of spatial proximity and selection tools in ArcGIS, bat species shape files were integrated with structures of interest. Throughout the project, IAGAP-based predicted bat distribution was referred as "potential bat presence."

As shown in Figure 3, some species are more common across Iowa than others; specifically, some cover a wider range/distribution due to their adaptability. According to the National GAP Species Data, species distributions were defined as the spatial arrangement of environments suitable for occupation by a species. In other words, species distributions were created using deductive models to predict areas suitable for occupation within a species range (USGS n.d.b). On the other hand, species ranges were defined as a coarse representation of the total area extent of a species or the geographic limits within which a species can be found. Table 2 shows distribution and range of bat species found in Iowa, using combined information from the Iowa and National GAP Species Data.

Table 2. Distribution and range of bat species in Iowa

#	Bat common name	Complete data		Location	Season
		Distribution	Range		
1.	Big brown bat *(Eptesicus fuscus)*	-	Yes	Statewide	All
2.	Tri-colored bat *(Perimyotis subflavus)*	Yes	Yes	Statewide	All
3.	Eastern red bat *(Lasiurus borealis)*	Yes	Yes	Statewide	Summer
4.	Evening bat *(Nycticeius humeralis)*	Yes	Yes	Southern (2/3)	All
5.	Hoary bat *(Lasiurus cinereus)*	Yes	Yes	Statewide	Summer
6.	Indiana bat *(Myotis sodalis)*	Yes	Yes	Southeast	Summer
7.	Little brown bat *(Myotis lucifugus)*	Yes	Yes	Statewide	All
8	Northern long-eared bat *(Myotis septentrionalis)*	Yes	Yes	Statewide	All
9.	Silver-haired bat *(Lasionycteris noctivagans)*	Yes	Yes	Statewide	All

Land Use

Land cover (land use) classifications for Iowa were obtained from the Iowa DNR. Classifications were derived from satellite imagery collected between May 2002 and May 2003 and presented at a 15 spatial meter resolution. There were 17 possible classifications:

- Barren
- Clouds/shadow/no data
- Bottomland forest
- Coniferous forest
- Deciduous forest
- Alfalfa/hay
- Planted grassland
- Grazed grassland
- Ungrazed grassland
- Roads
- Corn
- Soybeans
- Other row crop
- Water
- Wetland
- Residential
- Commercial industrial
- Unclassified

Land cover data were spatially integrated with sample bridge locations (which were previously integrated with other sources of data) at five incremental, buffer distances–0.1, 0.25, 0.50, 0.75, and 1.0 miles. These distances were utilized based on relevant literature and recommendations from the project monitor. Land classifications were aggregated for each bridge and buffer combination, and the percentage of each classification was estimated.

For comparison purposes, high-resolution land cover classifications for selected sample bridges within Iowa were obtained from the Iowa DNR. Classifications were based on three dates of aerial imagery, with a target interpretation year of 2009, as well as elevation data derived from aerial LiDAR. Fifteen different classes were derived and presented at a 1-meter spatial resolution.

Because of the high-resolution nature of the classification data, a statewide dataset was not available. Data were available only at the county level. This, in conjunction with the number of classification records associated with each county, created some challenges in data processing and analysis. Therefore, six sample bridges with somewhat diverse surrounding land cover were identified for comparison to the lower resolution (and older) land cover dataset. The high-resolution land cover data were spatially integrated with the six sample bridge locations at five incremental, buffer distances: 0.1, 0.25, 0.50, 0.75, and 1.0 miles. Land classifications were aggregated for each bridge and buffer combination, and the percentage of each classification estimated. As an example of the increased fidelity of the higher resolution data, the number of land classifications within 1.0 mile of a bridge increased by approximately 225 times, from approximately 36,000 to 8,136,000 records. An attempt was made to establish consistent classes between the low- and high-resolution datasets, and group classes as appropriate. A comparison of the land classification between high- and low-resolution data showed that the dominant land cover class for the bridges did not change while there were differences between the percentages of each class. Due to the rather substantial effort required to gather high-resolution land cover classification for each structure in the sample, the finding that the dominant land cover for the six selected bridges did not change for low- and high-resolution classifications, and time limitations; high-resolution land cover data were not gathered for the entire sample. However, GIS-based collection of land cover data in this study presented a unique approach for compiling quantitative land use data in comparison to other studies in this topic.

Bridge Sample

Initially, a random sample of 570 structures was selected from the database, which integrated the aforementioned data resources. During field inspections, some bridges could not be inspected due to traffic or time limitations. As a result, a total of 517 structures were sampled and inspected. Table 3 shows a comparison of the inspected sample versus statewide distribution of structure type (material).

Table 3. Sample distribution by structure type

Structure type (Material)	Sample structures		All Iowa structures	
	Count	**%**	**Count**	**%**
Concrete	49	9.5%	2,620	10.7%
Continuous concrete	63	12.2%	6,794	27.7%
Steel	70	13.5%	6,227	25.4%
Continuous steel	61	11.8%	1,910	7.8%
Prestressed concrete	77	14.9%	4,459	18.2%
Prestressed continuous concrete	52	10.1%	318	1.3%
Timber	100	19.3%	2,076	8.5%
Masonry	45	8.7%	82	0.3%
Total	**517**	**100.0%**	24,486	**100.0%**

Although the sample of structures was selected randomly, the distribution of the sample by location and structure type was checked to make sure the sample was reasonably representative of the population. Another concern during sampling was to make sure a sufficient number of locations with higher potential bat presence was selected in order to properly compare roosting sites with non-roosting sites. Figure 4 shows a map of all structures inspected. Green dots in Figure 4 represent the bridge locations with bat presence, while red dot represent bridge locations with no bat evidence present.

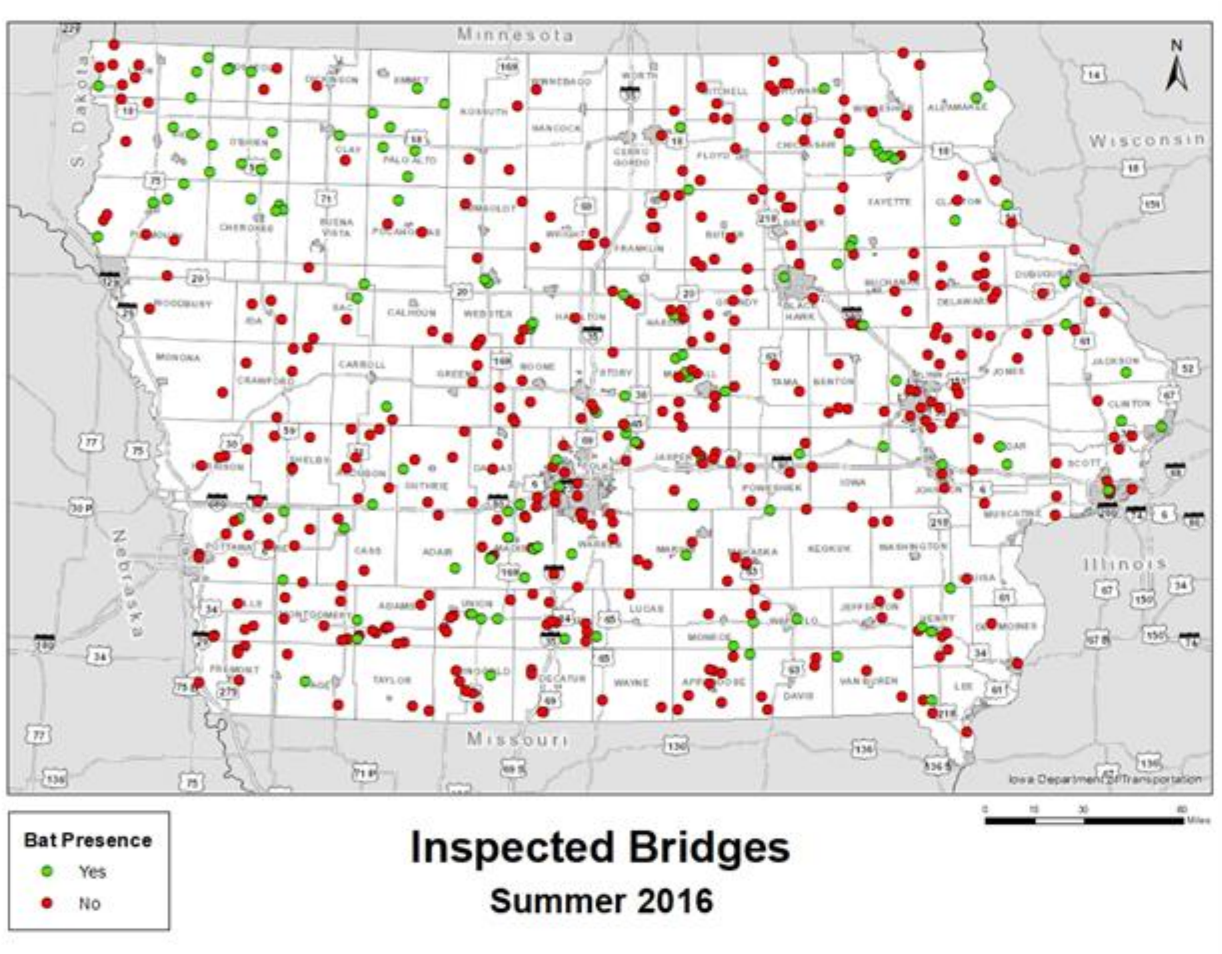

Figure 4. Map of inspected structures

Through use of Network Analyst tools in ArcMap, weekly routes were optimized to maximize travel time efficiency and ultimately increase sample size. In this process, supplemental bridges could be, and were, inspected in addition to the initial assigned sample for each week. Each team was provided with GIS-based maps of non-Interstate highway bridges surrounding the required sample sites to better facilitate identification of proximate bridges for possible inspection.

Field Inspection

In the summer months (May, June, and July) of 2016, sample bridges were inspected for bat presence. This effort was completed to acquire detailed evidence (FHWA/FRA 2015) of bat roosting at bridges. Such evidence could include bat droppings, visual sighting of flying bats, or presence of roosting bats. Items supplementing each inspected bridge structure included photographic and documented indications of the existence or inexistence of bats. The following are examples of some detailed attributes obtained from field reconnaissance:

- Bat presence/evidence (i.e., bat droppings, in-sight/flying, roosting)

- Roost type (crevice, plugged drain, swallow nests, etc.)
- Roost dimensions (i.e., height, depth, length)
- Condition surrounding roost (roadway, water, vegetation, etc.)
- Surrounding habitat (woodland, grassland, residential, etc.)

Figure 5 shows examples of tools used during structure inspections, including Pettersson Ultrasound Detector D240x (upper left), THruNite NC36 UT Flashlights (7300 lumens) (lower left), FLIRone infrared smartphone camera (upper right), and GoPro camera with 24-ft access pole (lower right).

Figure 5. Examples of tools used during field inspections

To collect the needed bat presence and structural characteristic information, four field investigation personnel with varied backgrounds were utilized. Team member backgrounds included engineering, bat ecology, and environmental science. Prior to conducting the data collection, each of the team members received two days of training that included information on use of inspection tools, signs of bat presence, indications of bat species, and bridge engineering terminology. Additionally, each team member was asked to evaluate and document two bridges for the presence of bats. These two bridges had been previously identified as one having and one not having bats present. Data from each of the teams were collectively evaluated with a detailed discussion following. During the data collection period, the data collectors worked in groups of two. To ensure that there was no team bias, the groups of two were mixed throughout the data collection period. Additionally, the various combinations of teams were asked to document the same bridges blindly. Following the duplicate inspections, a follow up session was held with each team to discuss any of the minor differences in collected data. In parallel, senior members of the research team conducted independent reviews of approximately 10 percent of the inspected bridges as part of the overall quality control/quality assurance (QC/QA) process. Table 4 lists the additional data items collected in the field.

Table 4. Data items collected in the field

Inspection Identification	**Bridge Components**	**Conditions Beneath Bridge (% of each)**
• Bridge Coordinates • Bridge Number • Team • Week • Day	• Superstructure Type • Height above ground (ft) • Superstructure depth (ft) • Number of spans • Substructure Type	• Bare ground • Vegetation • Flowing water • Standing water • Railroad • Roadway
General	**Roost Information**	**Traffic Information**
• Date • Time • Cloud cover • Temperature • County • Roadway • Bridge Number • Latitude • Longitude • Elevation (ft)	• Typical roost height (ft) • Typical crevice depth (ft) • Typical crevice length (ft) • Roost material	• Number of lanes below • Roadway material below • Roadway carried • Number of lanes • Roadway material • Estimated traffic (H/M/L)
Bat Presence	**Surrounding Habitat (% of each w/in 5 miles)**	**Data Collection Records**
• Bats present? • Visual? • Droppings? • IR? • Echo meter • Species • Number of bats • Number of Roosts	• Residential • Agricultural • Commercial • Woodland • Grassland • Mixed	• Photographs • IR Photographs • Bat sounds

Figure 6 presents several images from field inspections.

Figure 6. Pictures from field inspections

Analysis

In this study, logistic regression models were used to estimate the probability of bat presence based on bridge characteristics, potential bat presence, land cover, and field-collected data items. Within the logistic regression equation, the natural algorithm (LN) of the odds represents a logit transformation, where the logit function can be given as (Washington et al. 2011):

$$Y_i = logit(P_i) = LN\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \beta_3 X_{3,i} + \cdots + \beta_{K,i} X_{K,i} \quad (1)$$

where β_0 is the model constant (intercept) and $\beta_1, \dots . \beta_K$ are unknown parameters corresponding to the explanatory variables (X_K, k=1,…,K).

In Equation 1, the unknown binomial probabilities are a function of the explanatory variables. For this study, the unknown parameters in the models were estimated, as is typical, using maximum likelihood estimation. Using the estimated parameters, the probability that the outcome takes the value 1 (bats are present) can be estimated using

$$P_i = \frac{EXP[\beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \beta_3 X_{3,i} + \cdots + \beta_{K,i} X_{K,i}]}{1 + EXP[\beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \beta_3 X_{3,i} + \cdots + \beta_{K,i} X_{K,i}]} \quad (2)$$

When the value of an explanatory variable increases by one unit, and all other variables are held constant, the probability ratio can be represented as

$$\left(\frac{P_i}{1-P_i}\right)^* = \left(\frac{P_i}{1-P_i}\right) EXP\left[\hat{\beta}_i\right] \quad (3)$$

Here, $\hat{\beta}_i$ is the estimated parameter of the associated variable X_i. Thus, a one-unit increase in X_i increases the odds ratio $(P_i/(1-P_i))$ by the factor $EXP\left[\hat{\beta}_i\right]$.

Variables

As an initial step in the analysis, variables from all specified resources were examined for their statistical distributions, potential outliers, errors, and multicollinearity. A series of logistic regression models that estimate the probability of bat presence for single variables was also fit. Table 5 presents the most influential variables from these analyses, based on the highest McFadden's pseudo R-Square values.

Table 5. Most influential variables for bat presence

Variable	Type	Source	Pseudo R-square
Material	Categorical	NBI	13.56%
Superstructure type	Categorical	NBI	12.96%
Structure length (ft)	Numeric	NBI	9.58%
Superstructure height above ground (ft)	Numeric	Field	7.53%
Superstructure depth (0-2)	Categorical	Field	5.00%
Number of superstructure spans	Numeric	NBI	5.53%
Percentage wetland within 0.1 mile radius	Numeric	Land cover	4.84%
Deck width (ft)	Numeric	NBI	4.67%
Wetland within 0.25 mile radius (0,1)	Categorical	Land cover	3.14%
Substructure type	Categorical	NBI	3.61%
Road material	Categorical	Field	3.57%
Approach roadway width (ft)	Numeric	NBI	2.73%
Age	Numeric	NBI	2.16%
More Potential Bats (0,1)	Categorical	IAGAP	2.25%
Number of Potential Bats	Numeric	IAGAP	2.08%
Number of lanes	Numeric	NBI	1.63%
Percentage forest within 0.1 mile radius	Numeric	Land cover	1.38%
Percentage water within 0.1 mile radius	Numeric	Land cover	1.58%
Average Daily Traffic (ADT)	Numeric	NBI	1.57%
Percentage crop within 0.1 mile radius	Numeric	Land cover	1.18%

High pseudo R-square values indicate a good model fit. It should, however, be noted that high R-square values are rare in categorical models. Regardless, pseudo R-square is a measure of total uncertainty attributed to the model.

Bat presence, denoted with a 1 for presence and 0 for no evidence, was the dependent variable for the logistic regression models. Overall, 124 (24 percent) of the 517 structures had bat presence based on field inspections.

Among bridge characteristics, main structure type, which indicates structure material, was the most influential variable. Prestressed concrete continuous, prestressed concrete, and steel continuous structures had the highest probability of bat presence, respectively. This finding was consistent with the literature. Structure length and deck width were other influential bridge characteristics. With increased length and deck width, the probability of bat presence increased. This finding was also intuitive since larger structures typically have higher dimensions that could provide better shelter.

Superstructure height above ground and superstructure depth were the most influential variables among the ones collected in the field. Consistent with the literature, higher values for each variable increased the probability of bat presence significantly. Superstructure depth was presented with a categorical variable later in the analysis. Values smaller than 2 ft. (median) were coded as zero, values between 2 and 3 ft. were coded one, and values above 3 ft. were coded as two.

Wetland land coverage explained more of the uncertainty in the data with respect to other land cover variables. Only land cover variables for the smallest radius (0.1 mile) were significantly correlated with probability of bat presence at a 95 percent confidence level. Percentage wetland, forest, and water land cover had all positive parameter estimates, indicating increasing probability of bat presence for higher percentages, while percentage cropland cover had a negative parameter estimate.

Potential bat presence (IAGAP variables) also showed a significant relationship. The number of potential bats was a numeric variable with a minimum of zero, a maximum of nine, and a median of four, and had a positive parameter estimate. The categorical variable named “more potential bats” had a value of one when the number of potential bat species at a location was more than or equal to four (median value). This categorical variable explained the slightly higher variability in the model in comparison to the numeric variable.

Results

After fitting individual models, stepwise logistic regression analysis was done to select the final model that brings together the most relevant and significant variables, and explains the most variability in the data. Table 6 presents the final model that included three bridge characteristics, one land cover variable, and one variable on potential bat presence (Pseudo R-square = 17.9 percent).

Table 6. Parameter estimates of the final model

Parameter	Values	Estimate	Std. Error	ChiSquare	Prob>ChiSquare
Intercept		-2.869	0.383	56.18	<.0001*
Material (PS, PSCont, StCont-Others)	(1,-1)	0.608	0.124	24.09	<.0001*
Superstructure height above ground	(0-60)	0.101	0.027	14.17	0.0002*
Superstructure depth (0 & 1,2)	(-1,1)	0.508	0.245	4.29	0.038**
PCT Wetland (0.1 mi)	(0-31)	0.042	0.024	3.03	0.081***
More Potential Bats	(0,1)	0.548	0.271	4.09	0.043**

*Significant at 99% confidence level
**Significant at 95% confidence level
***Significant at 90% confidence level

The parameter notations for the categorical variables in Table 6 indicated the variable levels with respect to parameter estimates. For example, the material variable grouped together prestressed concrete continuous, prestressed concrete, and steel continuous structures, coded them as 1, and compared them to other structures (coded as -1 in the model). The superstructure depth variable grouped together the first two previously discussed classes (-1 and 1), and compared them to the final group with the deepest superstructures. The positive parameter estimates in Table 6 indicated a higher probability of bat presence for higher values of given parameters.

The parameter estimates for the variables and their values can be entered into Equations 1–3, in order to calculate predicted probabilities of bat presence for varying structures. For example, given a timber structure with a superstructure height above ground of 10 ft, superstructure depth less than 2.5 ft (class 1), 10 percent wetland land cover, and number of potential bat species of five (class 1); the probability of bat presence is estimated to be 12 percent. The probability increases to 31 percent if this structure is prestressed concrete. In a scenario where the same structure is prestressed concrete but percentage wetland land cover is 5 percent, the predicted probability of bat presence drops down to 27 percent. Overall, when the other variables in the models are fixed at a value, the odds of bats roosting on a bridge are 82 percent higher when structures are prestressed concrete continuous, prestressed concrete, or steel continuous.

In summary, the final model indicated that probability of bat presence on bridges increased significantly when structures were prestressed concrete continuous, prestressed concrete, or steel continuous; with increased superstructure height above ground; with increased superstructure depth; with increased wetland coverage within 0.1 mile radius of the structure; and with an increased number of potential bat species at the structure location.

FINDINGS AND RECOMMENDATIONS

Iowa Results

The final model, presented in the previous section, identified the most significant variables that impact the likelihood of bat roosting on Iowa bridges. Based on these variables, the likelihood of bat roosting can be estimated for the structures in the inventory, and also for future project locations. The findings provided the Iowa Department of Transportation (DOT) with the ability to proactively identify locations with a high likelihood of bat roosting.

To best represent local conditions, development of a state or region-specific predictive model is recommended and will be discussed in the following section. However, if alternate model development is not feasible, the Iowa model may potentially be used to screen for regions or structures with a higher likelihood of bat roosting. The model should only be applied with the understanding that the impacts of local conditions may not be entirely reflected. Necessary model inputs may originate from several sources. For example, bridge material may be obtained from the National Bridge Inventory (https://www.fhwa.dot.gov/bridge/nbi.cfm). The number of potential bat species and percentage of wetland cover within 0.1 miles may be obtained or derived from the National Gap Analysis Project (https://gapanalysis.usgs.gov/). Bridge superstructure depth and height above the ground may be obtained from other sources, such as original bridge plans or through field inspection.

Recommended Predictive Model Development and Implementation

The study presented here can be performed by any other state or agency. The literature review provided in this report gave an overview of relevant work for any researcher interested in the topic. Studying the relevant literature may help researchers who would like to do a similar study to identify potential variables or resources that should be considered for their area. It is also important to have an interdisciplinary project panel that can provide input to the researchers throughout their studies.

The data sources used in this study were either nationally available (NBI data, GAP data) or similar data sources that are potentially available for individual states (road data, land use data). It is critical to have a random sample of bridges for inspections, in order to have an unbiased sample that can be later used in statistical analysis. In this study, all data sources were spatially integrated, using structure locations as the key data element. This approach enabled the integration of other data sources when needed in later phases of the project. The variables to be collected during the field inspection were discussed and presented in this report. Researchers may add other variables that are relevant to their locations to this list.

The logistic regression model was an obvious choice for the statistical analysis and model development. Researchers may use other statistical models or analyses based on the findings they are interested in, or may add other questions of interest. Before the final model was developed, descriptive statistics for all model variables were examined. Logistic regression models were also fit for all single predictor variables. These initial models guided final model development and helped the research team define variable levels when it made sense to create ordinal variables from numeric continuous variables.

The findings from a similar study can be used by agencies to identify regions or structures with a higher likelihood of bat roosting. Such structures can be flagged for bat inspections, or the likelihood of bat roosting can be checked prior to any bridge project or during planning efforts. Including this information in the planning process at the outset may help agencies improve their overall planning processes.

Recommendations for Bridge Inspections

Before going to the bridge site, it is helpful to know what types of bridges may be most likely to be roosting locations, but it is important to remember, any bridge could be a roosting location. Places on bridges that have hidden or secluded spaces that could include crevices, large cracks, girders, expansion joints, or simply any spot that resembles cavern- or cave-like conditions should be carefully inspected. Even if there is no evidence of bat presence at a bridge during an inspection, it is important to keep checking during subsequent inspections because bats could later roost at that location. However, if a bridge has a known bat presence, it is good to document that, as bats may be more likely to return to the same place, particularly for maternity roosts. Agencies can consider having inspection items that help document bat presence over time.

During the field inspections, inspections are more likely to encounter evidence of bat presence such as urine staining or droppings, since actual bat sighting are uncommon. Bat urine stains typically look like brown splotches. The staining can also look like long lengths of browning, and the splotches can be various sizes. Bat guano looks like small, lumpy pellets. The pellets are typically black or dark brown in color, but older guano can look grey. The pellets may be in large or small piles on the ground, or guano may be found on bridge walls or support beams. The guano will often be spotted near or below evidence of staining. Bat droppings also will crumble into a powder when crushed. For the big brown bat, the most common species in Iowa, the pellets are about ½ in. long. For the small brown bat, also found in Iowa, the pellets are about the size of rice grains, but more lumpy in shape. The pellets could also be confused with rat droppings so look carefully to confirm all available evidence of bats. If droppings are the only evidence, inspect closer to identify if they are more likely from rats or mice. Rats and mice have smoother and sturdier droppings that tend to be tapered at the ends. Bat droppings are lumpy, tend to crumble, and are rounded at the ends.

Infrared cameras or echo meter tools can also be used to help identify bats at bridges. Both are available for use with smartphones, and they are easy to use. Go Pro-type cameras can also be attached to monopods to search for and photograph the presence of bats that otherwise might go undetected.

In some cases, identification of the roosting bat species may be necessary or desired. Such identification may be accomplished through various means, such as visual observation and acoustic monitoring. Species identification, especially through acoustic means, may require additional night visit(s) when the bats are more active.

The project team put together an instructional video on inspections for bat roosting at bridges. The video can be accessed at this link.

CONCLUSIONS

In one of the most comprehensive studies in the US, based on the number of bridges inspected, 517 structures were investigated for evidence of bat roosting. Logistic regression models were fit in order to identify structure, land cover distribution, and predicted bat species distribution characteristics that increase the probability of bat roosting. The final model indicated that the probability of bat roosting on bridges increased significantly when structures were:

- prestressed concrete continuous, prestressed concrete, or steel continuous
- with increased superstructure height above ground
- with increased superstructure depth
- with increased wetland coverage within 0.1 mile radius of the structure
- with an increased number of potential bat species at the location.

The findings showed that bridge characteristics, combined with land cover and bat species distribution data, can help identify locations with higher probabilities of bat roosting. This information can be useful to transportation agencies as they plan bridge replacement/repair/ rehabilitation projects and can help conservation efforts targeted toward bats. To the authors' knowledge, the integration of GIS-based objective land cover data with potential bat presence data, and estimation of quantitative and relative influence of variables on probability of bat roosting are unique to this study.

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