BATS IN AMERICAN BRIDGES

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Summary

Bridges and culverts were evaluated as bat roosting habitat in 25 states at elevations from sea level to 10,000 feet. Field surveys were conducted at 2,421 highway structures. Scientific literature was reviewed, and local biologists and engineers were interviewed, leading to the discovery of approximately 4,250,000 bats of 24 species living in 211 highway structures. Only one percent of existing structures had ideal conditions for day roosting, but at little or no extra cost a much larger percentage could provide habitat for bats in the future. Most species chose concrete crevices that were sealed at the top, at least 6 to 12 inches deep, 0.5 to 1.25 inches wide, and 10 feet or more above ground, typically not located over busy roadways. Retrofitting existing bridges and culverts proved highly successful in attracting bats, especially where bats were already using them at night.

Providing bat habitat in bridges or culverts, either during initial construction or through subsequent retrofitting, is an exceptionally feasible and popular means of mitigation that is highly cost-effective in demonstrating a proactive commitment to the environment. Advice for incorporating bat roosts, both before and after construction, is provided. Environmental and economic benefits, impacts on structural integrity and public safety, and management of occupied structures are discussed.

This document is available to the public online at www.batcon.org.

Cover photo by Merlin D. Tuttle
Back cover photo by Karen Marks

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Bat Conservation International

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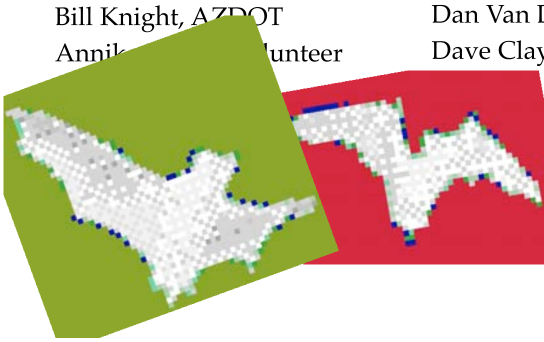

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The Importance and Needs of Bats

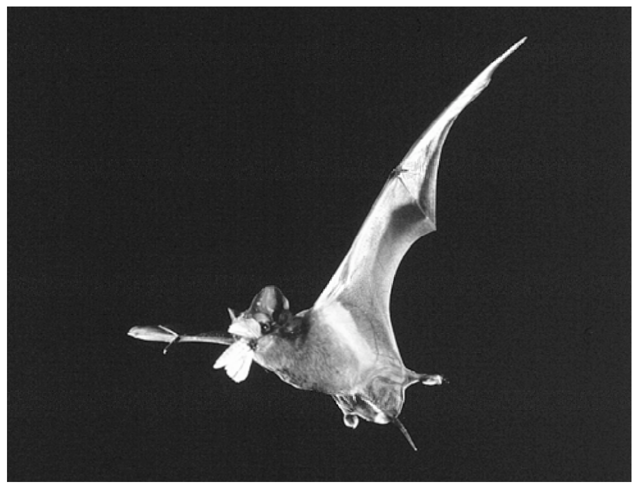
Contemporary engineers are students "of the engineering sciences": materials, structures, fluids, electricity, light, heat, energy, chemicals, systems—all the phenomena that constitute the physical universe. Underlying these engineering sciences are three fundamental disciplines: mathematics, physics, and chemistry—and increasingly, a fourth: biology.
—Samuel Florman, The Introspective Engineer

BATS ARE an indispensable natural resource. As primary predators of insects that fly at night, they are essential to the balance of nature. Bats also consume enormous quantities of insect pests that cost farmers and foresters billions of dollars annually.

Mexican free-tailed bats (*Tadarida brasiliensis*), common bridge-dwellers across the southern U.S., intercept northward migrations of America's most costly agricultural pest, the corn earworm moth (Figure 1). In Texas, these bats consume an estimated 2 million pounds of insects each night, reducing migrations of these and other pests that affect farmers throughout the U.S. farm-belt and as far north as Canada (McCracken, 1996) (Figure 2).

One bat can easily eat 20 female corn earworm moths in a night, and each moth can lay as many as 500 eggs, potentially producing 10,000 crop-damaging caterpillars. Yet as few as eight caterpillars per 100 plants can force a farmer to apply pesticides, demonstrating the impact of even small bat colonies.

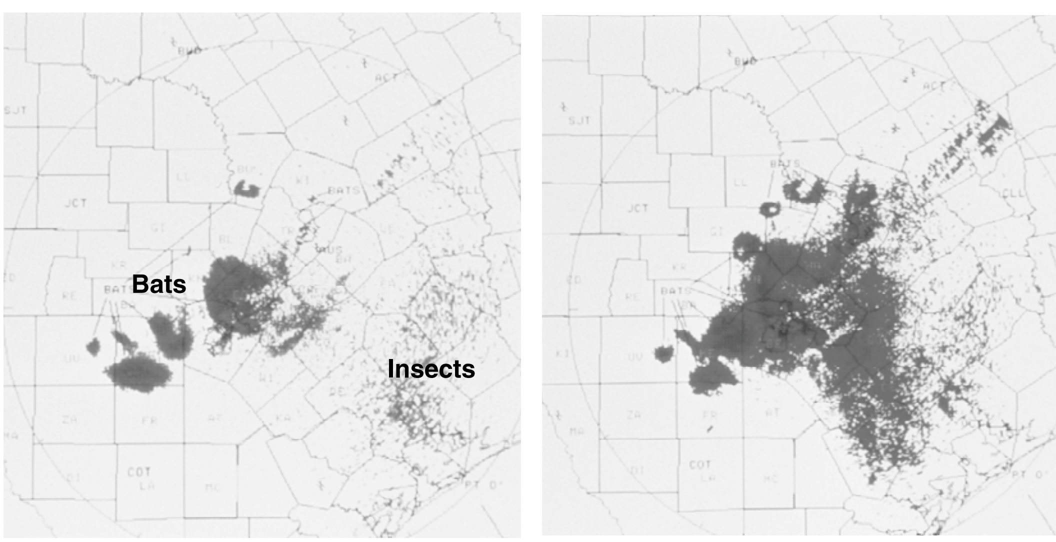
Unfortunately, more than half of America's bats, even species traditionally viewed as common, are endangered or declining in numbers sufficient to warrant concern. Bats are especially susceptible to extinction because most species form large colonies in vulnerable locations, such as caves, and produce only one pup per year. Colonies numbering in the millions have died when their roosts were disturbed or destroyed. As a consequence of losing natural roosts in caves and old growth forest snags, bridges and culverts have become havens of last resort.



MERLIN D. TUTTLE/875-5302

Figure 1. *Mexican free-tailed bat eating a corn earworm moth (Helicoverpa zea).*

Figure 2. *Doppler radar images reveal large bat emergences spreading to engulf concentrations of insects rising for crop lands where corn earworm moths are primary pests.*



COURTESY OF TPWD/ 910-2409

COURTESY OF TPWD/ 910-2411

The Benefits of Bats and Bridges

TWENTY-FOUR of the 45 U.S. species of bats have been documented to use highway structures as day and night roosts, and based on their known preferences at least 13 others are likely to do so. Although only one percent of American highway structures provide ideal day roost conditions, minor modifications in the design of future structures could easily provide homes for millions of bats.

Transportation departments can incorporate bat roosting spaces as a key element of on-site mitigation, to demonstrate proactive commitments to the environment, aid farmers, and gain positive publicity, often at little or no extra cost to the taxpayer (Figure 3).

The Congress Avenue bridge in Austin, Texas, clearly illustrates the economic and ecological benefits of bats in bridges (front cover). In the early 1980s, modifications to the bridge began attracting Mexican free-tailed bats. Citizens panicked when local media portrayed bats as dangerous (Figure 4). But fear quickly turned into appreciation as Austinites learned that the estimated 1.5 million bats consume 10 to 15 tons of insects each night, and their spectacular emergences attract tourist dollars. The Texas Department of Transportation, Bat Conservation International, and the City of Austin designed and installed viewing areas and educational kiosks, as well as bilingual signs warning people not to handle grounded bats. Now the citizens have proudly dubbed Austin the "Bat Capital of America," and the bridge is listed as a top tourist attraction on the City of Austin Web page. Each year, it attracts tens of thousands of tourists from all over the world.

BRIAN KEELEY/913-5402

Figure 3. Many of America's leading magazines, newspapers, and television shows have covered the bats and bridges story.

The Bats in American Bridges Project compiled this report to help transportation departments provide bat habitat where appropriate while avoiding it where nuisances could result. The report describes nationwide survey results for bat use of highway structures, preferred roost characteristics, roost enhancement techniques, and information on how state transportation departments are handling bat-related issues.

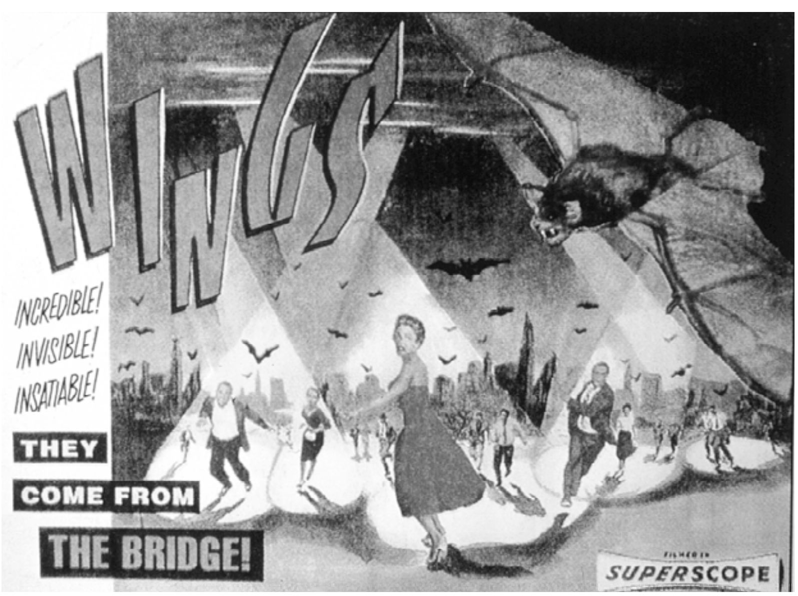


Figure 4. Sensational media stories caused panic by portraying the bats in Austin's Congress Avenue bridge as dangerous animals.

National Survey Design

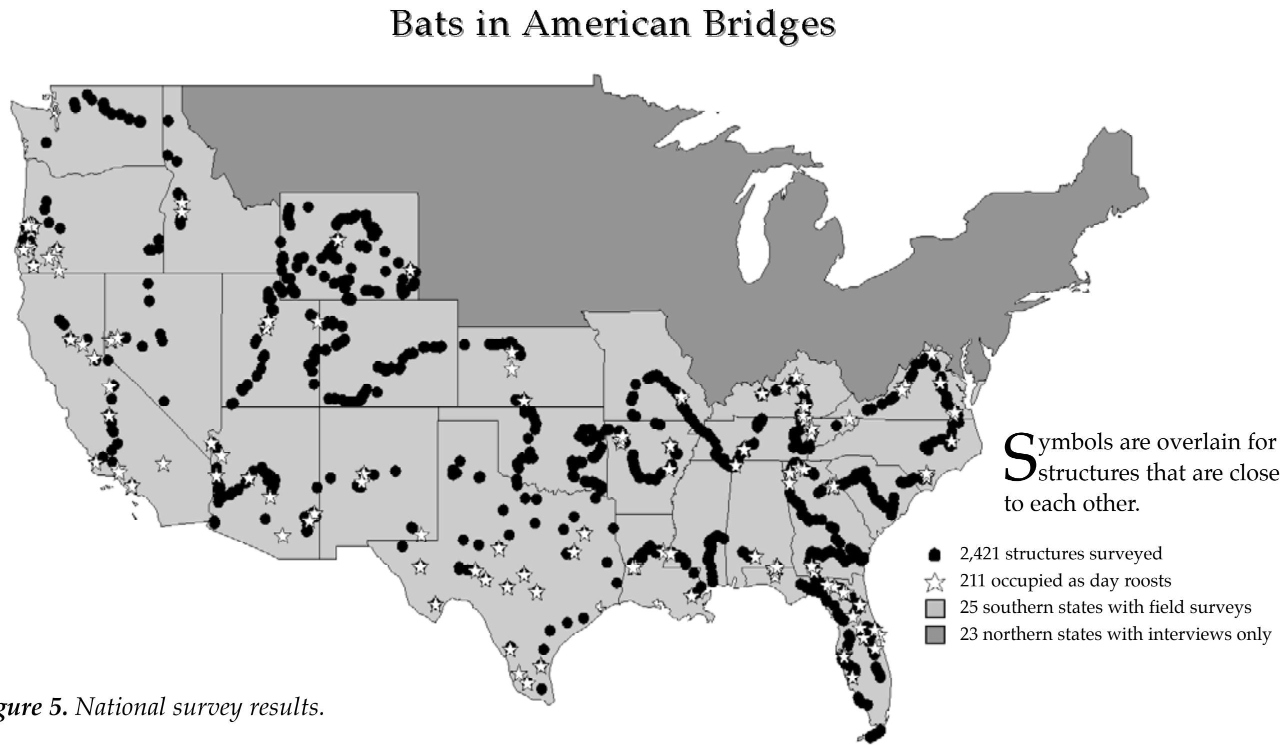


Figure 5. *National survey results.*

Figure 6. *This Idaho bridge sheltered a nursery colony of several hundred little brown myotis, the northernmost colony discovered during the survey.*

BRIAN AND ANNIKA KEELEY/911-1409

FIELD STUDIES, literature reviews, and interviews with biologists and engineers were conducted to determine which bat species use American highway structures, to identify their roosting preferences, and to develop methods of predicting where bats will use them.

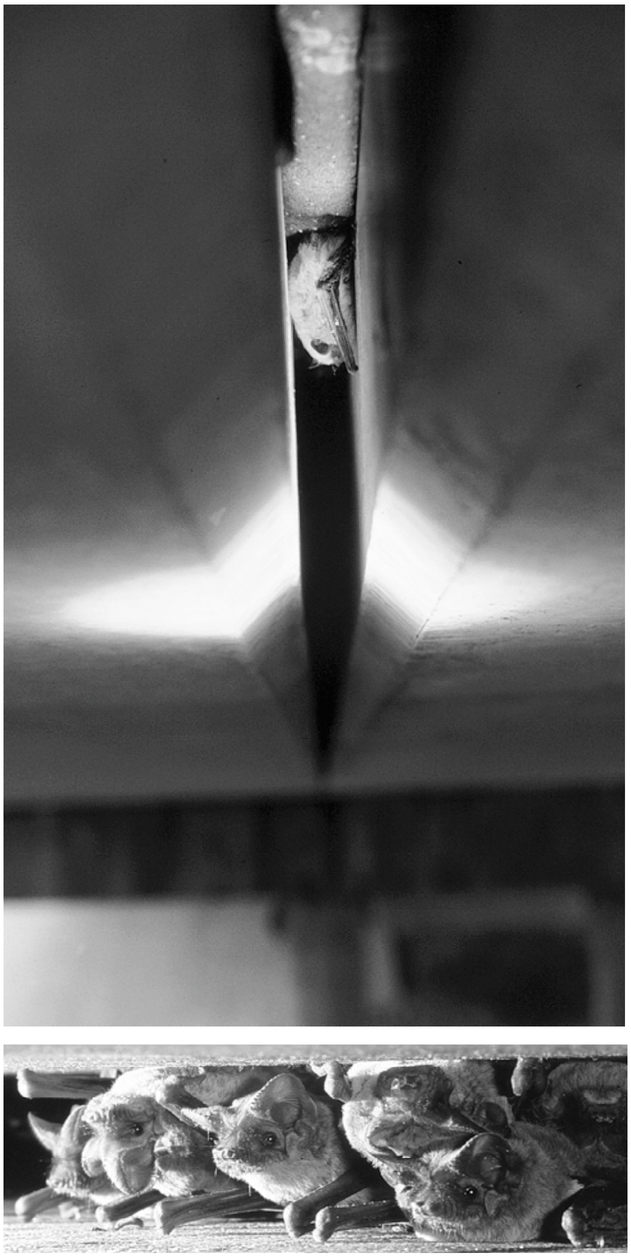
A total of 2,421 structures (1,312 bridges and 1,109 culverts) were surveyed for bat use along a route that passed through 25 states primarily in the southern half of the U.S. (Figure 5). Sixty different characteristics were used to determine bat roosting preferences. Sample survey forms are available in Appendix II.

Field surveys were impractical for bridges and culverts in the remaining 23 northern states because few are warm enough to meet bat needs. For these states we relied only on interviews. Hawaii has no bats likely to use highway structures.

Characteristics Bats Prefer

BATS USE HIGHWAY STRUCTURES either as day or night roosts. Day roosts are places that protect bats from predators and buffer weather changes while resting or rearing their young. Such roosts are usually in expansion joints or other crevices (Figure 7). In contrast, night roosts, where bats gather to digest their food between nightly feeding bouts, are often found in open areas between bridge support beams that are protected from the wind (Figure 8).

Two hundred and eleven highway structures were used as day roosts and 94 percent were occupied by crevice-dwelling bat species. Seven hundred and fourteen highway structures were used as night roosts. Day and night roost survey totals are listed in Appendix V.



BRIAN KEELEY/ 912-5501

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Figure 7. *Bridge crevices provide ideal day roost conditions for a fringe-tailed myotis (upper) and these Mexican free-tailed bats (lower).*

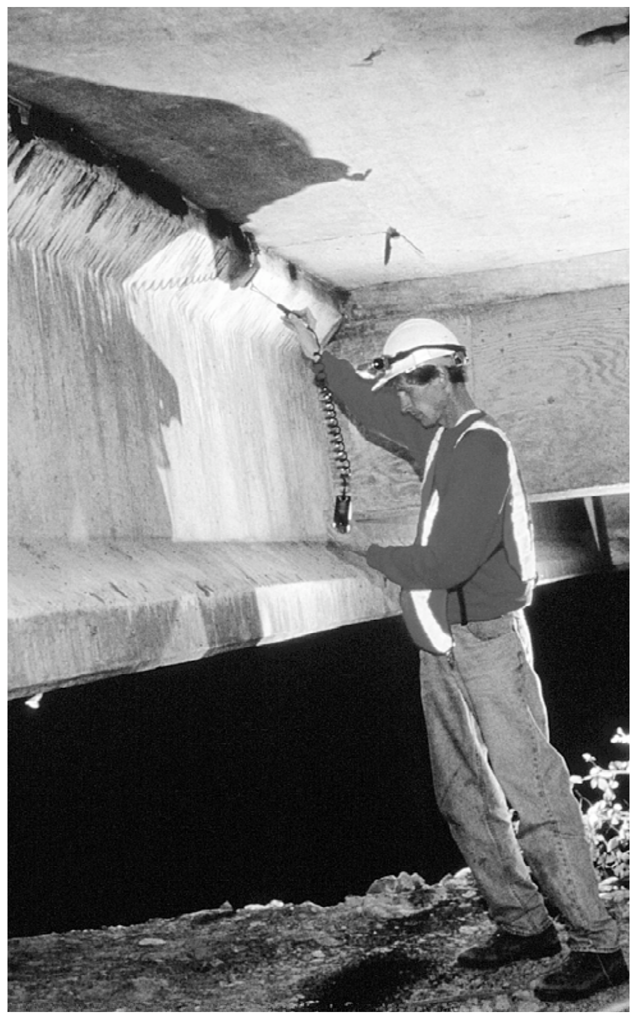

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Figure 8. *Night roosts are usually located in open spaces between bridge beams.*

Ideal Highway Structure Roost Characteristics

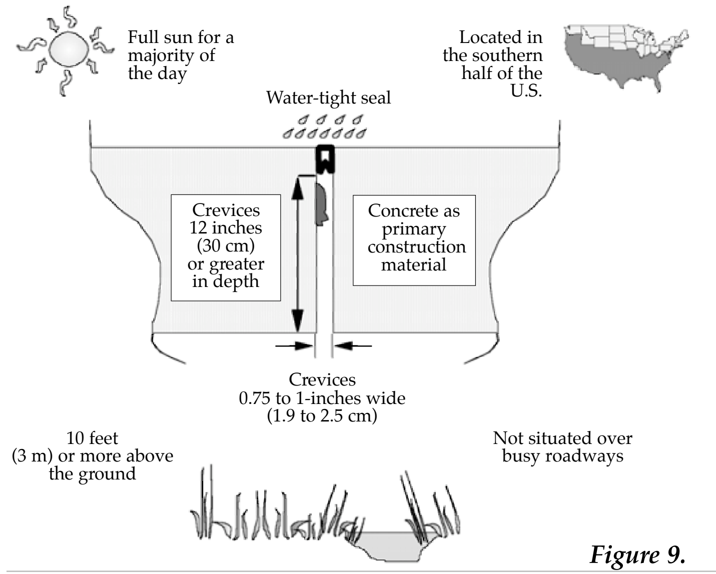


Figure 9.

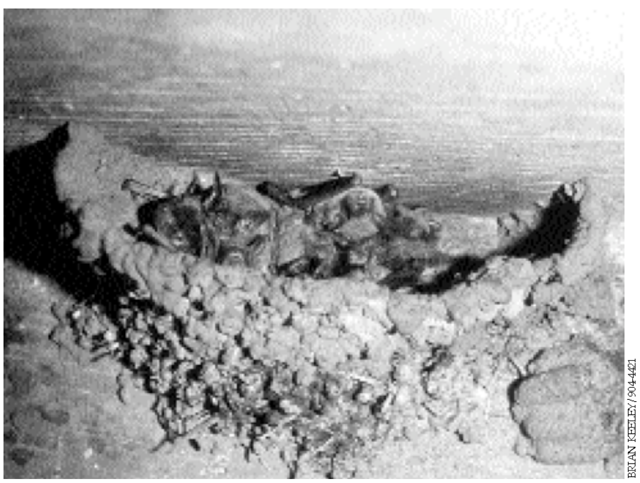


Figure 10. *Cave myotis were found using swallow nests in concrete box culverts.*

Day Roosts

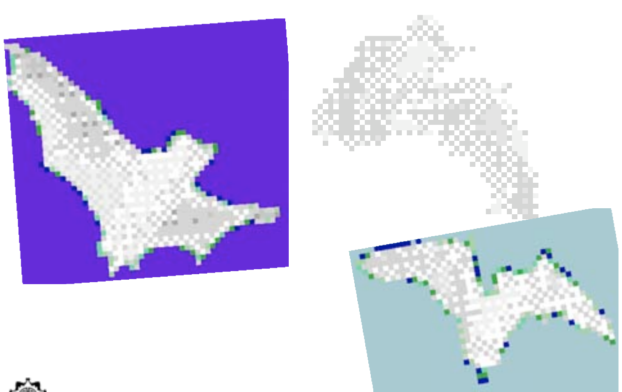
Only 281 of the 2,421 structures surveyed had characteristics that met the minimum needs of day-roosting bats. Ideal day roost characteristics for crevice-dwelling bat species that use highway structures, include (in descending priority):

Bridges (Figure 9):

- location in relatively warm areas, primarily in southern half of the U.S.
- construction material: concrete
- vertical crevices: 0.5 to 1.25 inches (0.25 to 3 centimeters) wide
- vertical crevices 12 inches (30 centimeters) or greater in depth
- roost height: 10 feet (3 meters) or more above the ground
- rainwater-sealed at the top
- full sun exposure of the structure
- not situated over busy roadways

Culverts:

- location in relatively warm areas
- concrete box culverts
- between 5 and 10 feet (1.5 and 3 meters) tall and 300 feet (100 meters) or more long
- openings protected from high winds
- not susceptible to flooding
- inner areas relatively dark with roughened walls or ceilings
- crevices, imperfections, or swallow nests (Figure 10)



Bats use parallel box beam bridges as day roosts more than any other kind (Figure 27, page 31). The next most preferred bridges are cast in place or made of prestressed concrete girder spans. These designs are the most likely to contain spaces suitable for bats. Although parallel box beam bridges were rarely encountered during the survey, they can provide numerous crevices of suitable width. Metal and small concrete culverts are the most frequently encountered highway structures and are the least preferred as roosts.

We found substantial variation in the frequency with which bats used suitable highway structures as either day or night roosts. Even ideal structures were rarely used by bats in areas dominated by open plains, perhaps due to a lack of appropriate habitat. Figure 12 compares average use rates with habitat types according to the major ecoregions defined by Bailey, 1995 (Appendix VI).

Many of the day-roosts were found in open crevices exposed to weather and predation, making them highly vulnerable to disturbance and injury by humans or vehicles (Figure 11). Although concrete is the preferred roost material, bats sometimes used wooden roosts or, when desperate, metal.

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Figure 11. *Desperate for roosts, this nursery colony of Alabama big brown bats (Eptesicus fuscus) roosts in an open crevice, exposed to disturbance from traffic and the weather.*

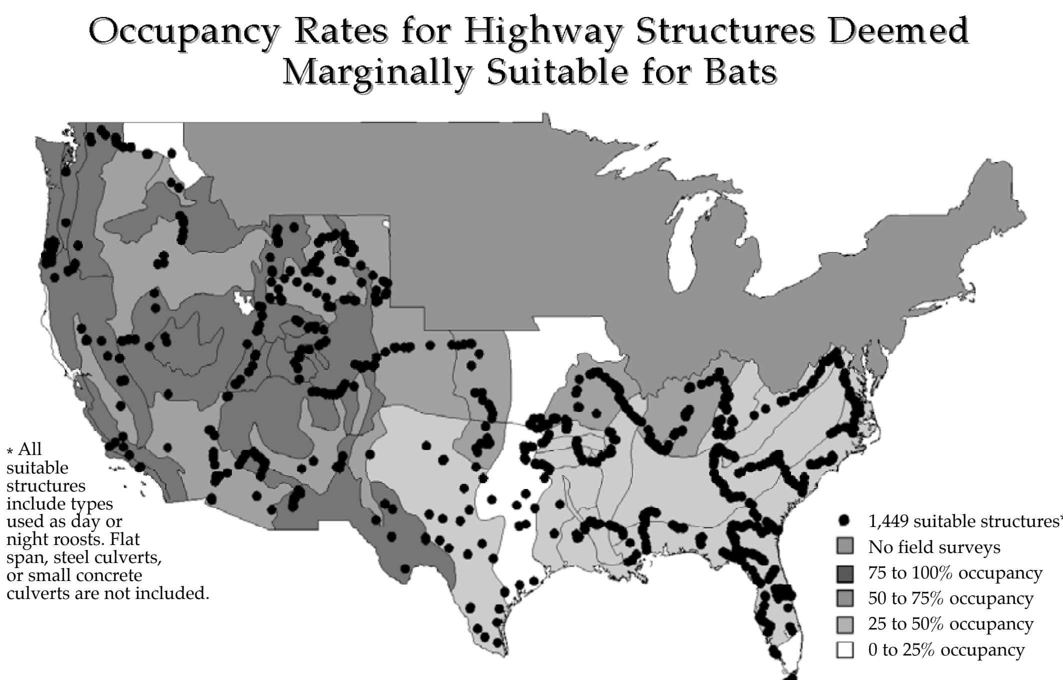

Figure 12. *Highway structure use patterns by ecoregion (See Appendix VI)*

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Figure 13. *An estimated 35,000 cave myotis raise their young in this south Texas culvert.*

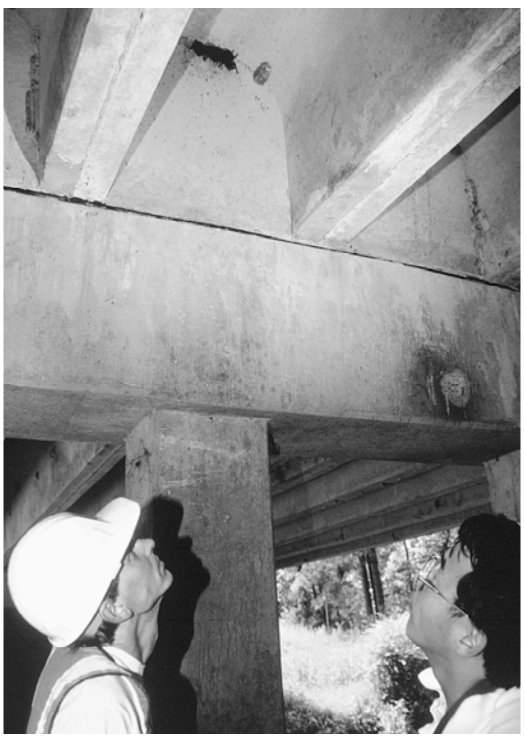

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Figure 14. *Lei Jin of the Louisiana Department of Transportation and Brian Keeley examine a Rafinesque's big-eared bat colony roosting in the open beams of a bridge.*

Night Roosts

Bats frequently use highway structures as night roosts. In fact, 29 percent of all structures surveyed had signs of night-roost activity. In some regions of the southwest, all suitable structures were used by night-roosting bats.

Night-roosting bats are believed to be attracted to bridges that provide protected roosts and have a large thermal mass that remains warm at night. Bridges constructed of prestressed concrete girder spans, cast-in-place spans, or steel I-beams are preferred. Vertical concrete surfaces located between beams provide ideal protection from wind and are especially used when they are heated by full sun exposure. Bats typically do not use bridges with flat bottomed surfaces that lack inter-beam spaces. They will avoid small culverts but will roost at night in the long concrete box culverts that often pass under divided highways, if the culverts are at least 5 feet (1.5 meters) tall.

Bats use night roosts in bridges mostly between 10 p.m. and midnight. Some remain for most of the night, periodically feeding and returning to digest their meals. Night roosts appear to play important roles in body temperature regulation and social behavior.

Species Preferences

Seventeen of the twenty-four species reported to use bridges or culverts were encountered during the field surveys (Figure 16). Occupied day roosts ranged in size from a single male to nursery colonies with more than one million mothers and their pups. Bridges and culverts are used by both bachelor and nursery colonies, and as temporary roosts during migration and mating. Culverts were sometimes also used for hibernation in southern areas.

Mexican free-tailed bat *(Tadarida brasiliensis)* colonies were found in southern bridges and culverts from coast to coast. Although most colonies are composed of fewer than 100 individuals, Mexican free-tailed bats have the potential to form bridge colonies numbering in the millions. The largest colonies exist in Texas, New Mexico, Arizona, and California.

Big brown bats *(Eptesicus fuscus)* were the second most abundant bridge-dwellers. This species represented 21.5 percent of the day-roosting colonies encountered. This species was found throughout the U.S. in small colonies ranging from two to seventy individuals.

Cave myotis *(Myotis velifer)* colonies represented 19 percent of the roosts encountered. Most were small with two to 10 individuals, but one nursery colony in a south Texas culvert included approximately 35,000 individuals (Figure 13). Abandoned swallow nests were regularly used.

The evening bat *(Nycticeius humeralis)* and most of the remaining myotis species were typically found in colonies of 2 to 200 individuals in bridge crevices, although some colonies consisted of more than 1,000. Southeastern myotis *(Myotis austroriparius)* use both bridges and culverts as nursery roosts, sometimes with as many as 2,000 to 3,000 mothers and their pups.

Unlike other bridge-dwelling species, both eastern and western pipistrelles *(Pipistrellus subflavus and hesperus)* and both Townsend's and Rafinesque's big-eared bats *(Corynorhinus townsendii* and *rafinesquii)* were found roosting in the open between bridge beams (Figures 14 and 15). Rafinesque's big-eared bats were found rearing young between open beams in low bridges darkened by thick vegetation bordering the sides. In one case a colony of big-eared bats abandoned its roost immediately after vegetation was removed. They returned three years later, when it had regrown (J. MacGregor, pers. comm.). In the southwest, individual male Townsend's big-eared bats were occasionally found roosting in 5-foot diameter (1.5 meters) or larger corrugated metal culverts. The nectar-feeding Mexican long-tongued bat *(Choeronycterus mexicanus)* has been reported using small diameter corrugated metal culverts (18 to 24 inches/45 to 61 centimeters) as day roosts in Arizona. Evidence of night roosting by small groups of nectar feeding bats was found in Arizona bridges.

Maternity colonies of both the endangered gray myotis *(Myotis grisescens)* and Indiana myotis *(Myotis sodalis)* live in bridges. Hundreds to thousands of gray myotis were found rearing their young in long concrete box culverts in three states.

The most frequent night roost signs encountered appeared to be from the genus *Myotis.* Similar signs from big brown and big-eared bats were also common regionally. Although Mexican free-tailed bats seemed to prefer to use their roost crevices as both day and night roosts, they were sometimes found night roosting in large numbers between open bridge beams and in long, tall concrete box culverts.

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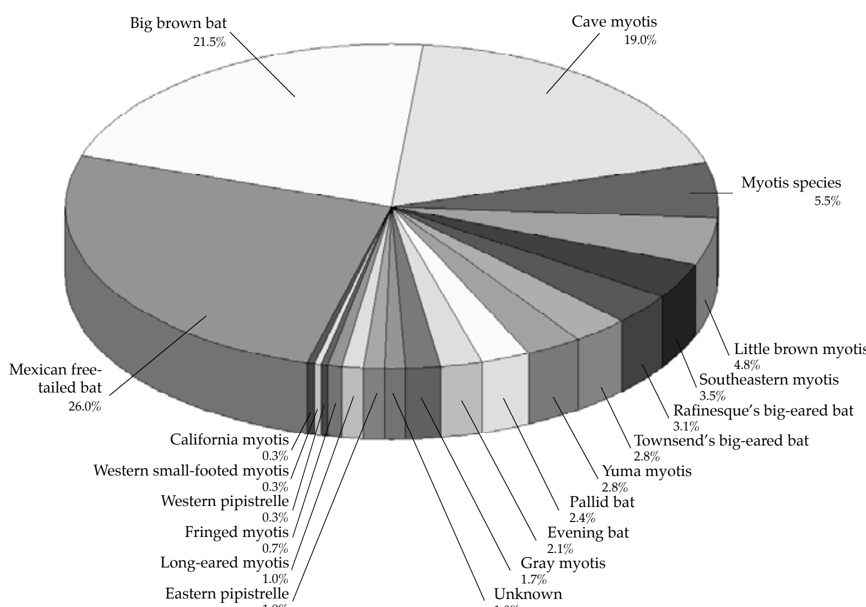
Figure 15. *Unlike crevice-dwelling bats, pipistrelles will day roost between open beams.*

Figure 16. *Species in Occupied Structures*



Bats and Highway Structure Temperatures

BATS HAVE THE LARGEST SURFACE AREA to body mass of any mammal, and this requires greater energy to maintain body temperatures. Sun-warmed bridges help adult bats to conserve energy and foster development of their young.

During the summer months, sun-exposed bridges act as thermal sinks, often achieving and holding temperatures above the ambient average for most of the 24-hour cycle (Figure 17). Comparisons of ambient and bridge temperatures from roosts in Kentucky, Texas, Oregon, and California show a similar pattern (J. MacGregor and D. Clayton, pers. comm.). The higher, more consistent bridge temperatures are especially important in mountainous or desert regions where ambient temperatures fluctuate dramatically within a 24-hour cycle.

An Oregon study found that bats prefer bridges with greatest sun exposures. Bridges receiving no sun had little or no bat use. This preference was especially obvious within partially shaded bridges, where roosting activities occurred only in the sun-exposed halves of bridges (Keeley, 1998).

The northernmost day roost discovered in this study was occupied by a maternity colony of roughly 300 little brown myotis in an Idaho bridge at 44° north latitude. In the eastern U.S. we found occupied bridges as far north as Virginia and Kentucky and have reports of occupied bridges from Indiana and New Jersey. However, the number of day roosts appears to drop rapidly above 42° north latitude.

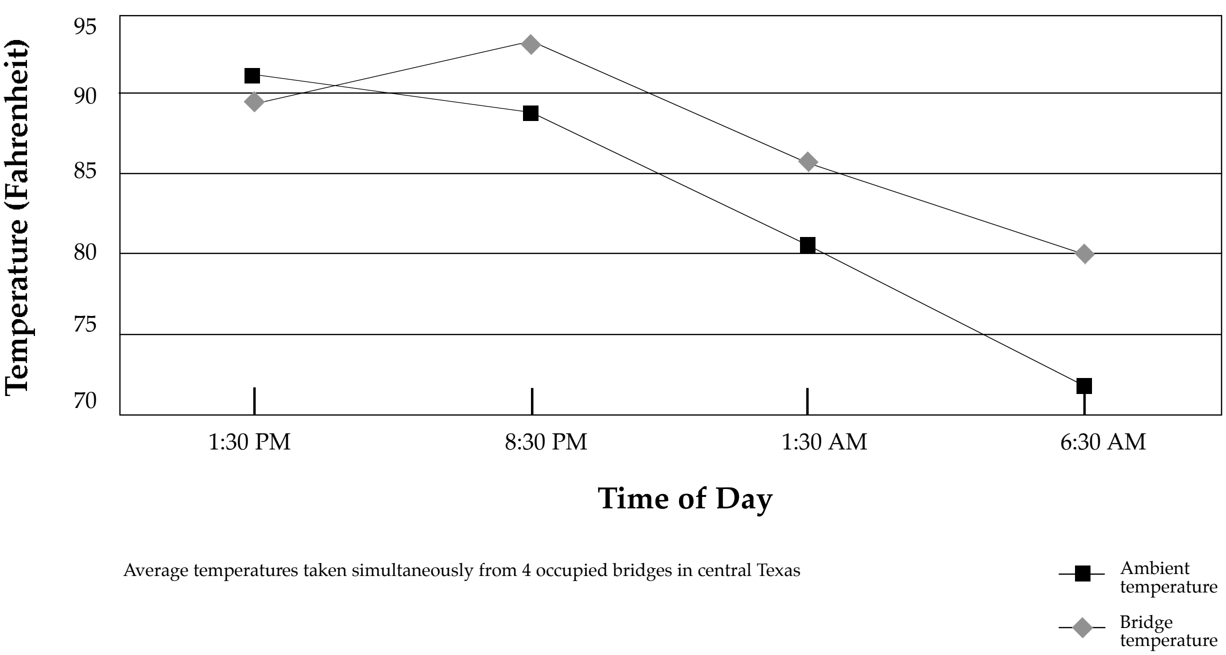


Figure 17. *Changes in Bridge Temperature over 24 Hours*

How to Evaluate Highway Structures for Bat Use

CONDUCTING SURVEYS using appropriate techniques can provide valuable information on where bats use highway structures and what characteristics they prefer. Evaluating bridges or culverts for bats or signs of bat use is easy if you know what to look for. Knowing where highway structures are used by bats alerts planners to areas where enhancement, mitigation, or exclusion projects may be most needed.

Conducting Surveys

The type of bat roosting information needed will determine the survey design. Educating bridge inspectors to recognize evidence of bat use can easily provide information on the distribution of bat-occupied structures. More detailed information or identification of species and their roost preferences can be obtained by trained biologists.

The Florida Department of Transportation asks its district bridge inspectors to include notes on bat roosts in their reports, which are periodically compiled by the environmental planning department. This type of survey adds little effort to existing workloads and inexpensively produces a statewide database of bat-occupied bridges in a relatively short period of time. The information is useful for planning structural maintenance schedules and predicting bat occupancy for mitigation projects.

Parallel box beam bridges with suitable crevices are the most frequently used highway structure design for day roosts. Lists of parallel box beam bridge locations are available from the bridge division of transportation departments. Surveying these bridges for bat use can provide quick assessment.

To more fully evaluate bat use patterns, a state can be divided into sections, either by districts or by geographic or ecological regions. Intersections can be selected along all major road types (interstates, U.S. highways, state highways, and county roads) within each section. From each intersection, equal distances are traveled down each roadway, surveying at least 30 structures. Using the data sheets provided in Appendix II, all information for each structure is recorded for later comparison. If needed, additional information about structures can be obtained from the Bridge Inspection and Appraisal Program (BRINSAP) files maintained by each state transportation department.

Survey Techniques

Evidence of use in occupied day roosts often includes visible bats, audible chirping, as well as droppings and stains from urine or body oils at or below the roost. Special equipment can be helpful in locating bat roosts and for identifying bats in unreachable locations. A high-powered rechargeable light (500,000 candlepower or greater recommended) combined with a pair of binoculars is useful for visual inspection of dark crevices or cavities from beneath the bridge or when looking inside culverts. Bridge crevices on roadways with low traffic loads can sometimes be inspected topside with a high-powered light. An electronic device called a bat detector can also be used to listen for high frequency vocalizations that would otherwise be inaudible to humans. A mirror or miniature camera lens mounted on a telescoping pole can aid inspections of otherwise unreachable locations (Figure 18).

Because suitable day roost conditions are rare in current highway structures, evidence left by night- roosting bats is the most reliable method for determining activity in the area. Night roost signs are usually found under the bridge on or below the warmest locations, such as between bridge beams, on vertical concrete surfaces, at the highest points (close to the road deck), and usually near the end abutments where the airflow is reduced. Appendix II provides survey forms useful for identifying preferred roosting characteristics in bridges and culverts.

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Figure 18. *To survey unreachable roosts, researchers use a camera lens attached to a telescoping pole.*

How to Create Bat Roosts in Highway Structures

Creation of day-roost habitat for bats in new or existing highway structures is easy, often at little or no extra cost to the taxpayer. For new structures, the minimum needs for day-roosting bats can be met by specifying the proper dimensions for crevices such as expansion joints (Figure 19). Retrofitting habitat into existing highway structures has become a popular and successful method of accommodating bats. Design plans for retrofitting bridges and culverts are available in Appendix III. Pre-surveys to look for bat signs in nearby bridges are useful to predict the success of proposed enhancement projects. Four bridges in Oregon (D. Clayton, pers. comm.) and five bridges and two culverts in Texas with signs of night roosting were retrofitted with ideal crevices, and all were occupied by bats within the first year. All retrofit designs tested in bridges and culverts so far have successfully attracted bats, and at least six states are already using retrofitting projects to accommodate bats.

Retrofitting projects have many appealing features for habitat enhancement. They

- are adaptable to almost any structure
- can be placed where they will have a high potential for success
- can be placed in locations that minimize disturbance from maintenance or vandalism
- can be sized to accommodate small or large colonies
- are beneficial to agriculture
- are inexpensive (can be constructed from recycled materials)
- can be expanded by adding additional units if initial efforts are successful
- can be easily moved if necessary

Two basic designs can be used to retrofit almost any bridge or culvert. Texas Bat-Abodes (Appendix III) can accommodate thousands of bats each, and have been modified to fit three different bridge designs. Four of the five tested were fully occupied, one within the first month (Figure 20).

The Oregon Wedge (Figure 21) can house several hundred bats and has been accepted for day roosting by 12 species, including a maternity colony of Yuma Myotis *(Myotis yumanensis)* in Oregon (D. Clayton, pers. comm.). This design has been successful in both bridges and culverts in Oregon, Arizona, and Texas. The Texas Department of Transportation developed a concrete version that also attracted bats within a year (Figure 22).

Locations with evidence of attempted bat use are ideal for retrofitting projects. Roadways with structures that pass through public lands, such as parks or national forests, are especially good candidates for bat habitat enhancement programs. In most cases, transportation department costs are minimal. In fact, local businesses are often willing to donate materials, assisting school children or private

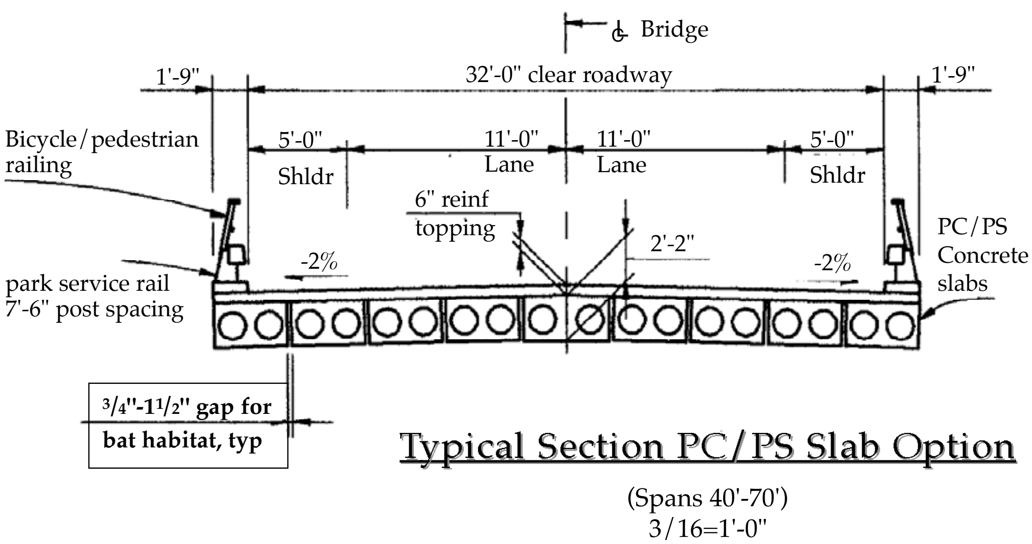


Figure 19. Actual bridge construction plan detail specifying appropriate width openings to accommodate bats in a specialized bridge type. Courtesy of Tom Barnard, LoBuono, Armstrong & Associates.

BRIAN KEELEY/ 913-5318

Figure 20. *Several designs of the Texas Bat-Abode, such as this one modified for a steel I-beam bridge, have been used to attract thousands of bats.*

BRIAN KEELEY/ 913-5407

Figure 21. *The Oregon wedge is inexpensive and easily installed. This design has successfully attracted 12 species of bats.*

agencies in constructing required structures. News media coverage and positive publicity of such projects has been extraordinary.

When 33,000 Mexican free-tailed bats became a nuisance in the attic of the Canadian Middle School in Canadian, Texas, teachers and students collaborated on a project to provide alternate roosts for up to 50,000 bats in a nearby highway bridge. They applied for, and received, an Environmental Challenge Program grant from the Texas General Land Office and H-E-B Grocery Company. Then they worked with Bat Conservation International and the Texas Department of Transportation to build and mount their roosts (Figure 23).

When old bridges must be replaced, some of those occupied by bats have been retained as wildlife sanctuaries. The Santa Barbara Public Works Department and the California Department of Transportation are collaborating to preserve a colony of 10,000 Mexican free-tailed bats and 200 pallid bats *(Antrozous pallidus)* by retaining a portion of an old bridge that is surrounded by agricultural fields

BRYAN HODGES

Figure 22. *The Texas Department of Transportation developed a concrete bat house that provides homes for hundreds of bats.*

(Storrer, 1994). It is calculated that these bats consume roughly 10,000 pounds (4,540 kg) of insects each summer, many of which are pests.

In Oregon the Departments of Transportation and Fish and Wildlife have cooperated in retaining a bridge occupied by a colony of Yuma myotis that had been slated for destruction (S. Cross, pers. comm.). Removal costs were avoided, while valuable wildlife habitat was protected.

Incorporating characteristics into new structures specifically for bats can be relatively inexpensive and easy to do. The Texas Department of Transportation has committed to construct a bat-friendly domed culvert (Appendix III). The cost to customize standard culvert designs is minimal, and modifications can even be implemented during construction (M. Bloschock, pers. comm.).

Bridge habitat enhancement techniques are also being developed in other countries. In Australia, the roost portion of an old wooden bridge was retained and incorporated into the underbelly of a new replacement bridge (G. Hoye, pers. comm.). In England, special bat-friendly bricks and concrete bat boxes have been provided to create roost spaces, and alterations to new bridge designs are being used to incorporate bat habitat into bridges during mitigation projects (Billington, 1997).

Figure 23. *Canadian Middle School students worked with the Texas Department of Transportation to install Texas Bat-Abodes that can accommodate up to 50,000 bats.*

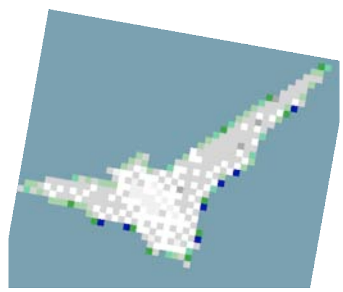
KATHY JACKSON

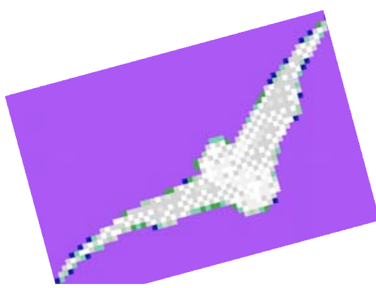
Mitigation

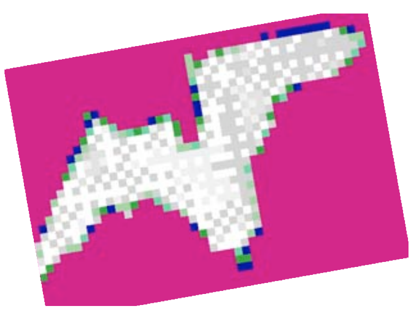
TRANSPORTATION departments faced with balancing human needs and sensitive wildlife issues will find incorporation of bat roosts into highway structures to be ideal for mitigation as well as for proactive habitat enhancement. Roadway construction negatively impacts bats both directly and indirectly. Roads built along rivers or rock faces can permanently destroy roosts in cliffs or caves within or near the right of way. In addition, road construction through riparian forests removes roost-bearing trees. Roads also increase human accessibility to sensitive roosts in caves or mines, forcing bats to abandon these roosts when they are disturbed. It is essential to minimize environmental damage, especially when state or federally listed endangered species are present.

Unlike many other mitigation efforts, bat roost enhancement projects for roadways can be conducted onsite. As described in the previous section, there are many options for helping bats in new or existing structures. For example, while planning a highway through the Tonto National Forest, the Arizona Department of Transportation and the U.S. Forest Service are collaborating on a project to incorporate bat habitat into a new highway bridge. The highway department is including mounting brackets in the bridge design plans, and the Forest Service is constructing artificial roosts that the highway department will install (R. Orr, pers. comm.).

Another means of providing alternative roosts is by retrofitting nearby highway structures with habitat or using free-standing bat house designs. There are commercially produced bat houses available that can accommodate up to tens of thousands of bats (see Bat Conservation International's Web site: www.batcon.org). These are ideal for use in off-site mitigation projects.







Commonly Asked Questions

Throughout this project, careful consideration has been given to questions of how bats in bridges or culverts affect people, the structures, and the environment. The following questions address those concerns.

What are the benefits of including bat habitat in highway structures?
The 1.5 million Mexican free-tailed bats from the Congress Avenue bridge in Austin, Texas consume approximately 10 to 15 tons of insects nightly, and these include large quantities of the most costly agricultural pests in the state (McCracken and Westbrook, in man.). The impact of even small colonies of bats in bridges can be considerable. Just 150 big brown bats (a common nationwide bridge-dweller) can consume enough adult cucumber beetles in one summer to prevent egg-laying that could produce 33 million of their costly root-worm larvae (Whitaker, 1995). Also, some insect pests tend to avoid areas where bat echolocation calls are heard (Belton and Kempster, 1962; Agee, 1964). Press coverage of projects to incorporate bat habitat into highway structures has been excellent and extremely positive.

Do bats affect structural integrity?
During the nationwide surveys, no structural damage attributable to bats was observed, nor were any reports of such damage received. Mark Bloschock, a Texas Department of Transportation bridge design engineer, inspected the Congress Avenue bridge and the University of Texas football stadium and found no damage of consequence within the normal life span of concrete structures. The bridge has been occupied for more than 15 years by approximately 1.5 million bats, the stadium 63 years by tens of thousands.

Organic materials that retain moisture, such as bat droppings, could facilitate oxidation on unprotected metal parts. Thus, bat roosts above exposed metal components should be discouraged.

Do bat colonies in highway structures negatively impact the environment?
During our nationwide surveys, no negative impacts on natural or human environments were observed, nor were any reported. Even exceptionally large bat colonies numbering in the hundreds of thousands have not been associated with environmental degradation. Two water quality studies were conducted on Town Lake beneath the Congress Avenue bridge bat roost by the City of Austin and the Lower Colorado River Authority respectively. These studies found a negligible impact caused by the bat colony (Lyday, 1994; Guajardo, 1995). Large guano deposits can produce odors in the immediate vicinity that are unpleasant to some people, though there are few complaints in Austin, despite having 1.5 million bats.

Will bat colonies interfere with maintenance schedules?
Bats roosting in highway structures are habituated to vibrations and sounds associated with normal traffic and will be minimally disturbed if maintenance operations create these conditions. Structural maintenance only affects bat colonies if the roost is

Figure 24. *Keith Hutson, Alabama Game and Fish Department, and Johnny Sims, Natchez Trace Parkway, inspect big brown bats raising young in an open crevice. Most bats leave in winter, but when summer work must proceed, workers can protect bats in crevices with tarps.*

BRIAN AND ANNIKA KEELEY/ 912-2415

suddenly exposed or if foreign materials (water, tar, gravel, etc.) are introduced. During our field surveys, we observed crews working on and around occupied structures without apparent effects on bats.

How can transportation departments minimize disturbance to bat colonies in highway structures?
Bats that occupy bridge crevices often ignore workers in the general area. Where work must be performed above crevices that are open at the top (Figure 24), disturbance can be minimized by covering them with tarps. Bats such as big-eared species, that roost in larger open areas between beams, are highly susceptible to disturbance, but they typically do not occupy bridges year round. Transportation departments can avoid accidentally providing roosts where bats are unwanted by minimizing the inclusion of preferred characteristics. (See page 11, Characteristics Bats Prefer.)

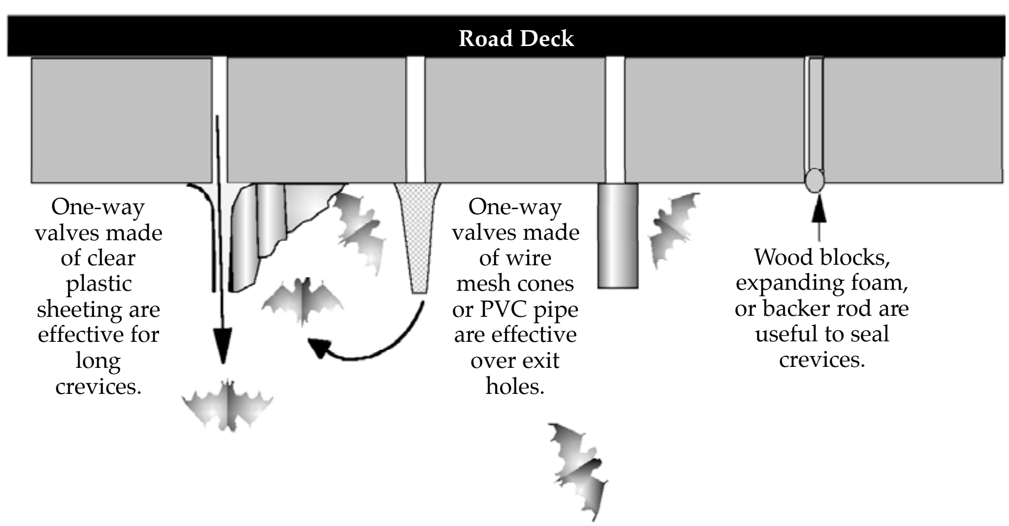
Timing Maintenance Activities
In most states, bats leave their summer bridge roosts to overwinter in more protected locations. Maintenance conducted between November 1 and February 1 will minimize disturbance. In the southernmost regions, where freezing temperatures rarely occur for extended periods some bats may remain year round. Still, proceeding with winter maintenance activities will affect fewer bats and avoid the disturbance of flightless young that would occur in summer. When questions arise, we recommend consultation with experienced bat biologists.

Exclusion
Excluding bats from a roost is a process that allows them to exit unharmed, but not re-enter. This reduces the potential for humans to come in contact with bats. If maintenance work has to be done while bats are in a roost, exclusion may be necessary. To conduct an exclusion, primary exit points are identified and marked. All other escape routes greater than 0.25 inch (0.6 centimeter) are sealed. Access to unused portions of long crevices can be minimized by filling them with suitable material, such as wood, backer rod, expanding foam, or caulk. Care should be taken to avoid sealing bats into the roost. A one-way valve is placed over the primary exit points to prevent re-entry. Simple one way valves have been constructed using wire mesh cones, PVC, and strips of clear plastic sheeting attached over exit points (Figure 25). Once the bats have been excluded, roost spaces can be permanently filled with a suitable substance. Bats do not chew or remove materials. Bats displaced during exclusions may try to return to the roost for a short time following the procedure.

The Florida Department of Transportation used all aspects of this process during reconstruction of a bat-occupied bridge. In order to minimize disturbance to the bats, the project was initiated during the winter months when the fewest bats were present. Properly sized wood strips were used to fill unused portions of the roost crevice, and one-way valves constructed of wire mesh were installed over the exit points. In this case, bats did not move into bat houses mounted on nearby poles within the project

Bridge Cross-Section Exclusion Diagram

Figure 25.



period, but the department hopes that the bats will return to roosts being built into the new bridge.

Educating Maintenance Workers
Before working near known roosts, maintenance crews should be taught not to handle bats and how to avoid disturbing them (Figure 26). Educational materials can be obtained by contacting state game and fish departments or Bat Conservation International, Inc.

Do bat colonies in a bridge or culvert pose human health or safety risks?
Most small bridge bat colonies pose no threat to humans and probably will remain unnoticed throughout the life of the structure. However, spectacular emergences of large bat colonies from highway structures can attract public attention, as has been demonstrated at the Congress Avenue bridge. Tens of thousands of visitors have come to view this spectacle each summer for more than a decade. Measures to minimize human contact as well as signs warning about handling bats may be needed at heavily visited locations. Even though the Congress Avenue bridge is located in the midst of a large metropolitan area, no one has contracted any disease from the 1.5 million bats in the 16 years since they arrived. A fence prevents access to areas where young or sick bats sometimes fall, and signs warn visitors not to handle bats.

Only two diseases, rabies and histoplasmosis, have been transmitted from bats to humans, and exposure risks are easy to avoid. Rabies can be transmitted only from the bite of a rabid animal or from contact between an infected animal's nerve tissue and an open wound. The virus is not found in urine or feces. The occasional bat that does contract rabies is almost never aggressive and becomes a problem only if handled. Any animal bite should be professionally evaluated as a potential rabies exposure. A safe, effective, and painless vaccine is now available, for either pre- or post-exposure protection.

Histoplasma capsulatum is a fungus that lives in soil enriched by animal droppings and can cause a respiratory illness called histoplasmosis, which is most often contracted from birds. Humans risk infection only when they inhale spore-laden dust.

Figure 26. *The Georgia Department of Transportation is learning about bats to help avoid problems during maintenance activities.*

BRIAN AND ANNIKA KEELEY / 912-2403

Bridge workers should minimize dust inhalation where there are either bird or bat droppings. A respirator capable of filtering 2 to 3 micron-sized particles should be worn in work areas where inhalation of dust from animal droppings cannot be avoided (Kunz, 1998).

How do endangered or threatened bat species affect transportation departments?

Transportation departments can often mitigate alteration of sensitive roost habitats by providing space for bats in highway structures. There are currently six federally endangered bat species on the U.S. mainland. The gray myotis *(Myotis grisescens)* has successfully used both bridges and culverts as maternity roosts. The Indiana myotis *(Myotis sodalis)* has been documented to use bridges as day roosts, but bridge suitability for this species remains poorly investigated. Although the two endangered big-eared bat subspecies (*Corynorhinus townsendii virginianus* and *C. t. ingens)* have not been documented in highway structures, western big-eared bats regularly use bridges as day roosts. Endangered lesser *(Leptonycteris curasoae)* and greater long-nosed bats *(Leptonycteris nivalis)* found in the extreme southwestern U.S., have not been documented using highway structures.

In contrast to other endangered plant and animal species, bats have a mobility and behavioral adaptability that allows greater bridge maintenance and replacement flexibility. Bridges or culverts occupied by endangered bat species often can be worked on without disturbing the bats by simply choosing a time when bats are not present. Varied mitigative measures are also available (see Mitigation).

How are transportation departments dealing with bats in highway structures?

The Federal Highway Administration was the lead agency initiating the national study of bat use of bridges followed by contributions from Texas, Florida, Georgia, Tennessee, Oklahoma, Wyoming, Utah, and New Mexico transportation departments. Individually, growing numbers of transportation departments are integrating bat management techniques into maintenance schedules. California evaluates every project for impacts to bats. Significant local wildlife resources and species of concern listed by the state or federal governments are given special consideration (G. Erickson, pers. comm.). The Arizona Department of Transportation also includes bats in its environmental impact statements with an emphasis on species of concern (T. Snow, pers. comm.).

The Texas Department of Transportation has conducted a statewide study of bat use in highway structures and is using the information to actively preserve and promote bat roosts where appropriate. Thousands of bats have new homes throughout the state in both bridges and culverts retrofitted with bat roosts. In south Texas, methods of trimming palm trees within the right of way have been altered to retain dead fronds where bats are roosting.

How important are highway structures to bats?

In many cases, bridges and culverts now serve as havens of last resort for bats that have lost their natural roosts in caves and old-growth forests. However, surrounding habitat often remains suitable, if only bats can find safe places to rear their young. Typically, where traditional roosts have been protected, or new ones have been provided, even endangered species are recovering.

Though less than one percent of American bridges are currently suitable for use by bats, these bridges already shelter millions of bats of at least 24 species, including some of our continent's most regionally important populations. The fact that bats were often found attempting to rear young in sites unprotected from rain, or where many were killed by passing cars as they emerged, demonstrates that roost shortages are common.

Roost loss and disturbance are the most important known causes of bat decline. Yet, as we have documented, bridges and culverts can provide essential substitutes. Transportation departments are ideally positioned to help reestablish one of America's most valuable wildlife resources at little or no cost to taxpayers, through highly popular proactive measures.

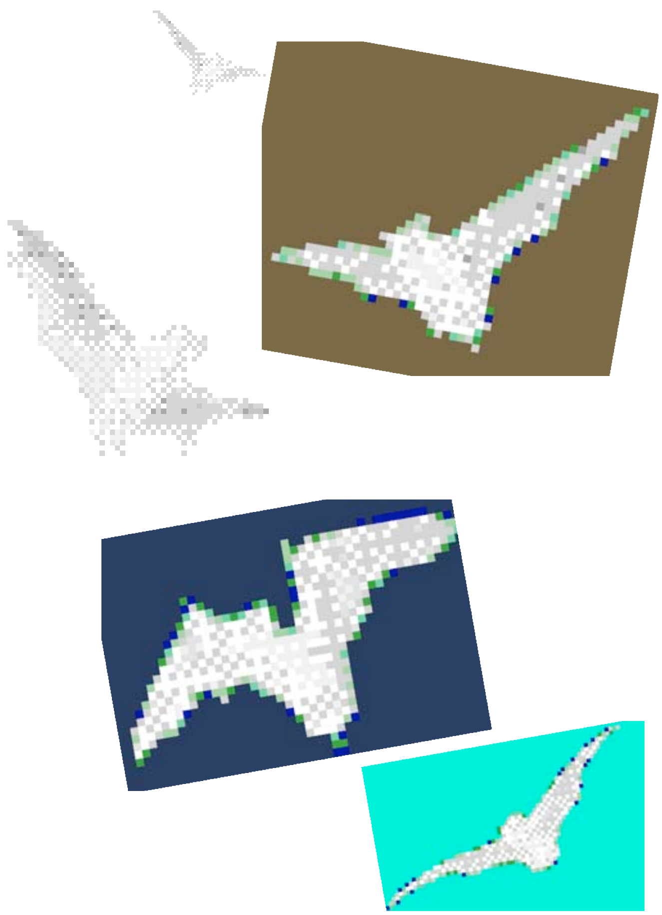
Bats are often forced into dangerous conditions when safe roosts are in short supply. In one instance, bats were found emerging from a bridge located over a busy highway where they were frequently hit by cars. In another instance, several hundred Mexican free-tailed bats died apparently from hypothermia during an early winter cold front, when rain leaked into an unsealed crevice soaking them. These incidents emphasize the importance of providing adequate conditions when planning habitat enhancement for bats.

Discussion

IT IS ESTIMATED that within the southern U.S., 3,600 highway structures are being used by approximately 33 million bats. The fact that 43 percent of bridges suitable for night roosting are used, indicates that in many areas bat habitat enhancement projects would be successful and could help stabilize bat populations by providing roosts needed for rearing young.

Other countries are also beginning to recognize the value of providing roosts in bridges and are initiating their own projects. Information from the Bats in American Bridges project has already been requested from 17 countries, suggesting that habitat enhancements in highway structures may become a powerful conservation tool worldwide.

As illustrated at the Congress Avenue bridge, the public has firmly demonstrated its support for bats in highway structures. Furthermore, research documenting the impact of bats in reducing crop pests is rapidly increasing support in the agricultural community. People support what they value, and the relationship between bats and highway structures is clearly valuable to both humans and bats.



Appendix I:
Bats that Use Bridges and Culverts

Common Name	Documented bridge/culvert use	Potential use	Roost type crevices or open beams	Preferences	U.S. distribution	Status
Peters' ghost-faced bat *Mormoops megalophylla*	no	yes			SW	
Mexican long-tongued bat *Choeronycteris mexicana*	yes		open	sheltered spaces	SW	Species of Concern
Lesser long-nosed bat *Leptonycteris curasoae*	no	yes			SW	Endangered
Long-nosed bat *Leptonycteris nivalis*	no	yes			SW	Endangered
California leaf-nosed bat *Macrotus californicus*	yes		open	sheltered spaces	SW	
Pallid bat *Antrozous pallidus*	yes		crevice	1 to 1.5 inches	SW	
Rafinesque's big-eared bat *Corynorhinus rafinesquii*	yes		open	sheltered spaces	E	Species of Concern
Townsend's big-eared bat *Corynorhinus townsendii*	yes		open	sheltered spaces	NW, SW	Species of Concern
Virginia big-eared bat *Corynorhinus townsendii virginianus*	no	yes	open	sheltered spaces	E	Endangered (subspecies)
Ozark big-eared bat *Corynorhinus townsendii ingens*	no	yes	open	sheltered spaces	SC	Endangered (subspecies)
Big brown bat *Eptesicus fuscus*	yes		crevice	0.75 to 1.5 inches	Nationwide	
Spotted bat *Euderma maculatum*	no	yes			NW, SW	Species of Concern
Allen's lappet-browed bat *Idionycteris phyllotis*	no	yes			SW	Species of Concern
Silver-haired bat *Lasionycteris noctivagans*	yes		crevice	0.75 to 1.25 inches	NE, NW, C, S, W	
Southwestern myotis *Myotis auriculus*	no	yes			SW	
Southeastern myotis *Myotis austroriparius*	yes		open/ crevice	0.5 to 1.0 inch	SE	Species of Concern
California myotis *Myotis californicus*	no	yes			NW, SW	
Western small-footed myotis *Myotis ciliolabrum*	yes		crevice	0.5 to 1.0 inch	NW, SW	Species of Concern
Long-eared myotis *Myotis evotis*	yes		crevice	0.5 to 1.25 inches	NW, SW	Species of Concern

Common Name	Documented bridge/culvert use	Potential use	Roost type crevices or open beams	Preferences	U.S. distribution	Status
Gray myotis *Myotis grisescens*	yes		crevice	0.5 to 1.0 inch	NE, SE	Endangered
Keen's myotis *Myotis keenii*	no	yes	crevice	0.5 to 1.0 inch	NW	
Small-footed myotis *Myotis leibii*	yes		crevice	0.5 to 1.0 inch	NE	Species of Concern
Little brown myotis *Myotis lucifugus*	yes		crevice	0.5 to 1.0 inch	NE, SE, NW, SW	
Eastern long-eared myotis *Myotis septentrionalis*	yes		crevice	0.5 to 1.0 inch	NE	
Indiana myotis *Myotis sodalis*	yes		crevice	0.5 to 1.0 inch	NE	Endangered
Fringed myotis *Myotis thysanodes*	yes		crevice	0.5 to 1.0 inch	NW, SW	Species of Concern
Cave myotis *Myotis velifer*	yes		crevice/open	0.5 to 1.0 inch	SW	Species of Concern
Long-legged myotis *Myotis volans*	yes		crevice	0.5 to 1.0 inch	NW, SW	Species of Concern
Yuma myotis *Myotis yumanensis*	yes		crevice	0.5 to 1.0 inch	NW, SW	Species of Concern
Evening bat *Nycticeius humeralis*	yes		crevice	0.5 to 1.0 inch	NE, SE	
Western Pipistrelle *Pipistrellus hesperus*	yes		crevice/open	0.5 to 1.0 inch	NW, SW	
Eastern Pipistrelle *Pipistrellus subflavus*	yes		open		NE, SE	
Florida mastiff bat *Eumops glaucinus*	no	yes			Florida	Species of Concern
Western Mastiff bat *Eumops perotis*	no	yes			SW	Species of Concern
Underwood's mastiff bat *Eumops underwoodi*	no	yes			SW	Species of Concern
Pallas' mastiff bat *Molossus molossus*	no	yes			Florida	
Pocketed free-tailed bat *Nyctinomops femorosaccus*	no	yes			SW	
Big free-tailed bat *Nyctinomops macrotis*	yes		crevice	1 to 1.5 inches	SW	Species of Concern
Mexican free-tailed bat *Tadarida brasiliensis*	yes		crevice/open	0.5 to 1.25 inches	SE, SW	

Appendix II:
Survey Forms

THE FOLLOWING FORMS may prove useful in evaluating highway structures for actual or potential bat use. Some field experience may be necessary prior to initiating the surveys to develop familiarity with potential roost locations within structural designs. June is the best time of the year to conduct surveys, since nursery colonies are most detectable when rearing young.

Location

Sample #	Date	State	County	Highway type: Interstate	Highway type: U.S. Hwy.	Highway type: State	Highway type: County	Latitude	Longitude	Altitude	Ecological region
1											
2											
3											
4											
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7											
8											
9											
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Bats/Roost Types

Sample #	Bats present yes/no	Species	# of bats	# of species	Day roost yes/no	Nursery roost yes/no	Night roost intensity	# of roosts	Roost type: crevice	Roost type: plugged drain	Roost type: swallow nests	Roost type: imperfection or other
1												
2												
3												
4												
5												
6												
7												
8												
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Bridge Night Roost Index:

0 No sign of droppings or urine stains.

1 Small amount of such signs in only one location.

2 Small urine stains and scattered droppings in several locations.

3 Moderate dropping accumulations. Urine stains obvious within the bridge.

4 Large dropping accumulations. Fresh urine stains obvious and widespread.

5 Dropping accumulations several inches thick in several locations. Roosting evident throughout structure. Fresh urine stains in all optimal locations.

Structure Design

Sample #	Parallel box beam	Pre-stressed girder	Cast in place	Steel I-beam	Flat slab	Other: specify	Concrete box culvert: # of barrels and height	Concrete round culverts: diameter	Metal culvert: diameter	Ideal* crevices present yes/no
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
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* Evidence of storm-water staining along the length of the crevice indicates that it is not sealed and should not be considered as an ideal roost.

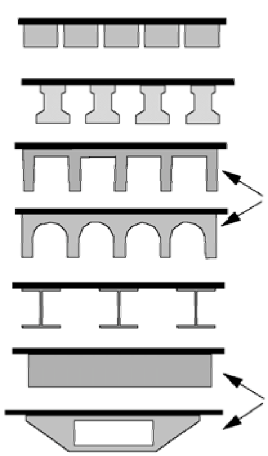

Figure 27. *Cross-sections of Common Bridge Designs*

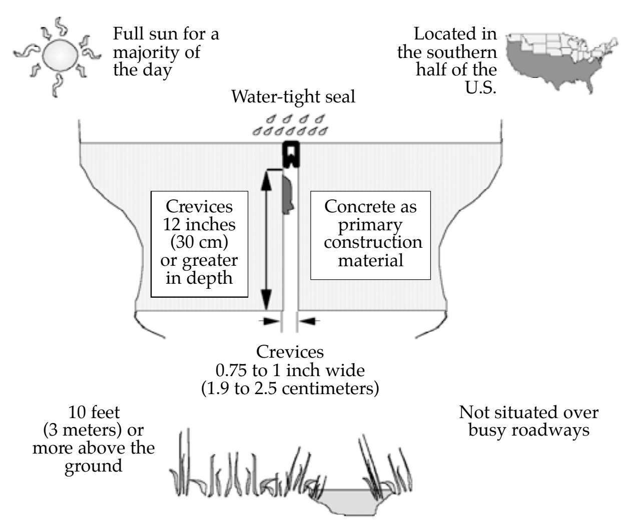

Figure 28. *Ideal Highway Structure Roost Characteristics*

Roost Substrate and Dimensions

Sample #	Roost Height Av.	Height Max.	Height Min.	Crevice Roost Width Av.	Crevice Width Max.	Crevice Width Min.	Crevice Depth Av.	Crevice Depth Max.	Crevice Depth Min.	Crevice Length	Roost Surface Concrete	Roost Surface Metal	Roost Surface Other
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2													
3													
4													
5													
6													
7													
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Surrounding Habitat

Sample #	Residential	Agriculture	Commercial	Woodland	Grassland	Ranching	Riparian	Mixed
1								
2								
3								
4								
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Conditions Beneath the Roost

Sample #	Bare ground	Open vegetation*	Closed vegetation†	Flowing water	Standing water	4-lane + highway	2-lane highway	Dirt road	Railroad	Concrete
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
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* Vegetation not blocking flight path within 10' of bridge underside or more than one entrance of a culvert.

† Vegetation interfering with bat access to potential roosts, either blocking bridge underside or both ends of culverts.

Appendix III:
Retrofitting for Bats

BAT-FRIENDLY HABITAT can be provided in either new or existing bridges or culverts, at little or no extra cost to taxpayers. During construction planning, there are no costs for an engineer to specify the appropriate crevice widths of 3/4 to 1 inch (1.9 to 2.5 centimeters) for expansion joints or other crevices. Existing structures can be retrofitted with bat-friendly habitats using the designs described in the following sections. *All retrofitting activities must be coordinated with appropriate transportation departments.* Signs of bat use in nearby bridges and culverts increase the chances of success for habitat enhancement projects.

The Texas Bat-Abode, Big-eared Bat-Abode, and the Oregon Bridge Wedge bat roosts are designed for day-roosting bats in bridges and culverts. In the protected environment of a bridge or culvert, a properly constructed and installed bat habitat made of quality materials should last as long as the highway structure.

Texas Bat-Abode

The Texas Bat-Abode is designed to retrofit bridges with bat habitat for crevice-dwelling species. It has an external panel on either side and 1 by 2 inch (2.5 to 5.1 centimeter) wooden spacers sandwiched between 0.5 to 0.75 inch (1.2 to 1.9 centimeters) plywood partitions (Figure 29). Recycled highway signs are ideal construction materials. Note that only the external panels need to be cut to fit the bridges' inter-beam spaces. The internal partitions should provide crevices 0.75 inch (1.9 centimeters) wide and at least 12 inches (31 centimeters) deep.

Smooth roost surfaces need to be textured to provide footholds for bats on at least one side of each plywood partition (preferably both), creating irregularities at least every 1/8 inch (0.3 centimeter). Many methods have been tested to create footholds, such as:

- using rough-sided paneling
- coating the panel with a thick layer of exterior polyurethane or epoxy paint sprinkled with rough grit
- attaching plastic mesh with silicone caulk or rust-resistant staples
- mechanically scarifying the wood with a sharp object such as a utility knife
- lightly grooving the wood with a saw (do not penetrate to the first plywood glue layer)
- lightly sandblasting the wood with rough-grit

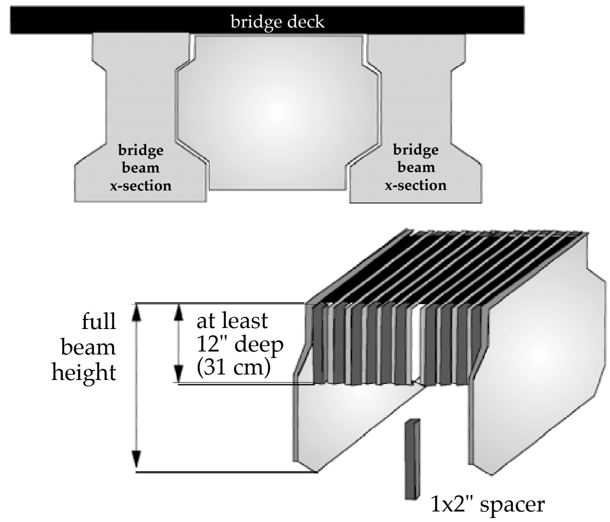


Figure 29. *Texas Bat-Abode for crevice-dwelling species.*

The use of rough-sided paneling or polyurethane-sprinkled with grit have provided the longest lasting results. Rust resistant wood screws should be used to assemble the spacers and partitions.

The Texas Bat-Abode should be installed in bridges that are at least 10 feet above ground, free of vegetation, and not susceptible to flooding or easy vandalism. Measurements of the exact location where the Bat-Abode is to be placed will ensure a proper fit. The number of partitions is arbitrary and limited only by availability of materials and support for the weight of the Abodes. Because of the weight, it may be easiest to assemble the cut pieces in the bridge. In wooden bridges, the unit should be anchored to the structure with heavy-duty rust-resistant lag-bolts.

Big-eared Bat-Abode

Big-eared bats are frequent bridge users in both the eastern and western United States. They prefer open roost areas such as cave entry rooms, large hollow trees, darkened undisturbed rooms in abandoned houses, or between the darkened beams of quiet bridges over streams. The Big-eared Bat-Abode creates these conditions.

The Big-eared Bat-Abode has two external panels with 1 by 2 inch spacers that are used as braces to

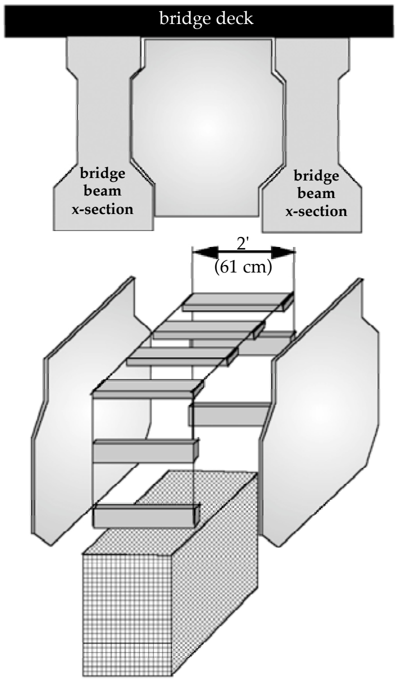


Figure 30. *Big-eared Bat-Abode.*

hold the panels together with a plastic mesh lining to provide footholds for bats. The netting should be attached using rust-resistant staples (Figure 30). The other methods of creating footholds mentioned above would also be effective.

It may be easier to partially assemble the structure on the ground leaving one end panel off until it is placed in its chosen location. Units installed in wooden bridges can be anchored using heavy-duty rust-resistance lag bolts. Because big-eared bats are very sensitive to disturbance, units should be placed in areas of low activity and painted a color that does not attract attention.

Big-eared bats are often found in low bridges darkened by thick vegetation growing along the sides. The Big-eared Bat-Abode should be placed at least six to 10 feet (two to three meters) above the ground in a secluded portion of the bridge. However, access to the fly-way entrance should not be blocked. Other bat species are also likely to use this structure.

The Oregon Wedge

The Oregon Wedge (Figure 31) is an inexpensive method of retrofitting bridges or culverts with day-roost habitat for bats. The Wedge is made from an 0.5 to 0.75 inch (1.2 to 2 centimeters) exterior grade plywood panel that is at least 18 inches high and 24 inches wide (46 by 61 centimeters) with three 1 by 2 inch (2.5 by 5 centimeters) wood strips attached along the top and sides, leaving an opening along the bottom.

If larger panel sizes are used, vertical wooden pieces should be placed every 24 inches (61 centimeters) to support the plywood and prevent warping. The pieces should not run from the top to the bottom so that bats can move about within the panel.

The Wedge can be attached to a vertical concrete portion of a bridge or culvert using concrete anchor-bolts or a fast-drying environmentally safe epoxy cement (such as 3M Scotch coat 3-12). *The transporta - tion department should install the panels if anchor bolts are used.* If the panel is to be attached to wood, then use appropriate rust resistant wood screws. Before applying the epoxy, check the preferred installation site to make sure the support strips fit flat against the concrete surface.

Wedge placement is possible on any adequately sized, flat concrete or wood surface. However, we

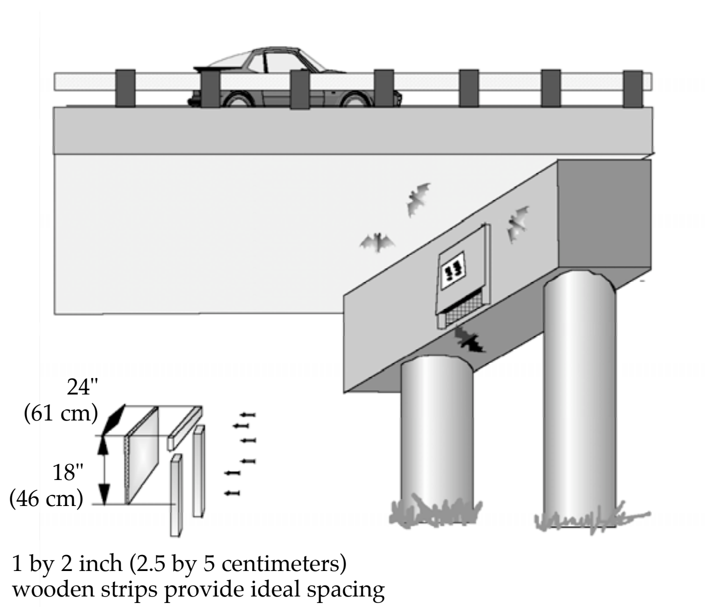


Figure 31. *Oregon Bridge Wedge. Designs courtesy of David Clayton and Dr. Steve Cross.*

recommend that the panels be placed near the sun-warmed road slab (preferably as high as possible between heat-trapping bridge beams). They should be at least 10 feet (3 meters) above ground, with a clear flyway (at least 10 feet), and be out of view or reach of vandals. The Wedge can also be installed in the middle sections of culverts higher than 5 feet (1.5 centimeters). A Wedge should not be placed in structures that flood. As a precaution against flooding, a 1.5 inch (3.8 centimeters) gap can be left at each corner where the support strips join to act as an escape route in the event of fast-rising water.

Bat-domed Culverts

The Bat-domed culvert (Figure 32) is a modified concrete box culvert designed to accommodate large colonies of bats. The dome has several bat-friendly characteristics:

- the height is increased
- warm air is trapped
- light intensity is reduced
- air movement is reduced

Bat-domed culverts should be at least 5 feet (1.5 meters) in height with an additional 1 to 2-foot (0.6 meter) raised portion centered in the culvert. The raised area can be any length from 2 to 50 feet, depending on the colony size preferred. The walls and ceilings of the raised area should be roughened to provide footholds for bats. The following method was used to produce suitable wall and ceiling textures. Using a crowbar, thin strips were removed from the surface of recycled plywood. The resulting roughened wood was then used as the form for pouring the concrete, which produced the desired textured surface within the domed area of the culvert. In addition, a method of attaching panels or partitions, such as female threaded inserts, can be incorporated into the raised walls and ceiling to create more surface area once the culvert is completed.

Bat-domed culverts should not be placed in areas susceptible to flooding. However, in the event of rising water, the dome may serve as a temporary air-trap. Almost any cave-dwelling species may use these, including several that are endangered.

Note: The 3M epoxy can be obtained by calling 1-800-722-6721. BCI would appreciate photographs of the installation and especially of bats using any bat-friendly modifications. For more information on adapting the designs to specific bridges, or to report occupied units, please contact: Brian Keeley, Bats and Bridges Project Coordinator, Bat Conservation International, Inc., P.O. Box 162603, Austin, Texas 78716. Phone (512) 327-9721. bkeeley@batcon.org

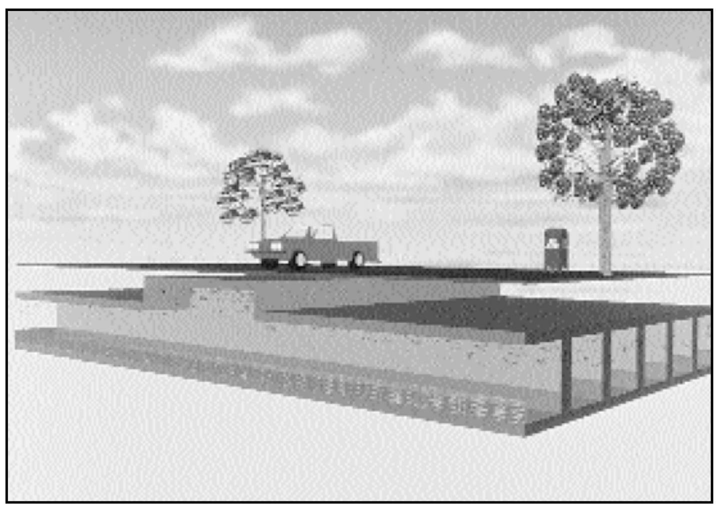
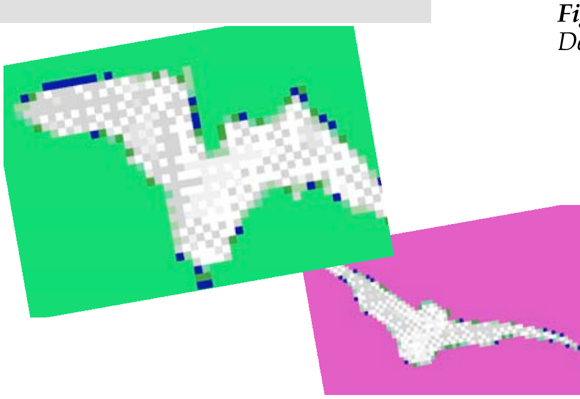
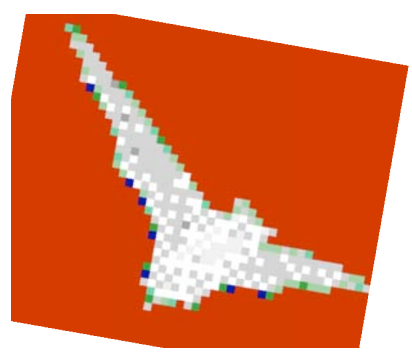


Figure 32. *Bat-domed culvert. Graphics courtesy of Texas Department of Transportation.*





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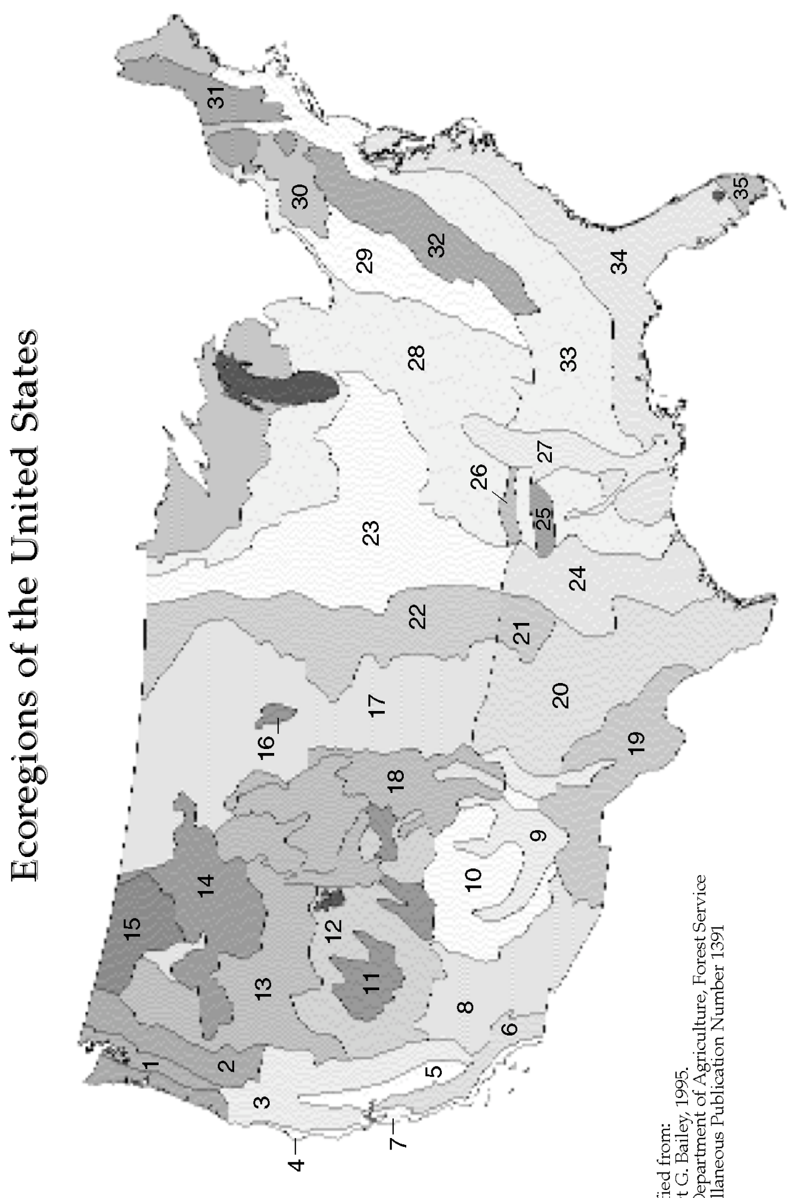
Appendix V:
State Survey Results

States field surveyed	Total number of highway structures surveyed	Total occupied day roosts	Total night roosts encountered
Alabama	13	5	1
Arizona	101	9	57
Arkansas	49	6	8
California	48	11	19
Colorado	50	0	31
Florida	142	29	22
Georgia	107	9	15
Idaho	30	2	9
Kansas	18	3	8
Kentucky	29	10	20
Louisiana	41	6	16
Mississippi	58	1	11
Missouri	37	2	17
Nevada	18	4	5
New Mexico	39	7	20
North Carolina	35	6	6
Oklahoma	66	0	13
Oregon	98	15	73
South Carolina	44	0	16
Tennessee	66	7	25
Texas	1060	62	156
Utah	58	4	40
Virginia	74	10	27
Washington	19	0	12
Wyoming	121	3	87
Total	2421	211	714

Appendix VI:
Ecoregions of the United States



Modified from:
Robert G. Bailey, 1995.
U.S. Department of Agriculture, Forest Service
Miscellaneous Publication Number 1391

Figure 12.

1. Pacific Lowland Forest
2. Cascade Mixed Forest
3. Sierran Steppe
4. California Coastal Steppe
5. California Dry Steppe
6. California Coastal Range
7. California Chapparal
8. American Semi-desert
9. Arizona-New Mexico Mountains Semi-desert
10. Colorado Plateau Semi-desert
11. Nevada-Utah Mountains Semi-desert
12. Intermountain Semi-desert and Desert
13. Intermountain Semi-desert
14. Middle Rocky Mountain Steppe
15. Northern Rocky Mountain Steppe
16. Black Hills Coniferous Forest
17. Great Plains-Palouse Dry Steppe
18. Southern Rocky Mountain Steppe
19. Chihuahuan Semi-desert
20. Southwest Plateau and Plains Dry Steppe
21. Great Plains Steppe and Shrub
22. Great Plains Steppe
23. Prairie Parkland (Temperate)
24. Prairie Parkland (Tropical)
25. Ouachita Mixed Forest (Continental)
26. Ozark Broadleaf Forest
27. Lower Mississippi Riverine Forest
28. Eastern Broadleaf Forest
29. Ouachita Mixed Forest (Oceanic)
30. Laurentian Mixed Forest
31. Adirondack-New England Mixed Coniferous Forest
32. Central Appalachian Broadleaf Forest
33. Southeastern Mixed Forest
34. Outer Coastal Plain Mixed Forest
35. Everglades

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