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EFFECTIVENESS OF LEDGES IN CULVERTS FOR SMALL MAMMAL PASSAGE

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16. Abstract

Ledges were installed in six culverts in Boulder County, Colorado, to test their ability to facilitate small mammal movement under roads and to determine whether Preble’s meadow jumping mice (*Zapus hudsonius preblei*) would use such ledges. Ledge use was measured by recording photographs of mammals on the ledge with motion-detecting cameras. Ledges connected to the streambank with removable ramps, which served as a proxy for rendering the ledges accessible in order to test whether there was more usage when the ramps were on (ledges accessible) than when they were off (ledges inaccessible). Nine mammal species were captured using the ledges in 705 photographs during the study spanning two summers, 2005 and 2006. Preble’s meadow jumping mouse was photographed on the ledge only once during the pilot and three times during the active study. There were 443 photographs of mammals on the ledge with ramps on and 262 photographs with ramps off. Significant differences were found among the six culverts and between ramp conditions. The ledges appear to present desirable passageways even with the ramps off, to the extent that small mammals will climb up concrete walls to access them. Culvert dimensions and vegetative cover did not show statistical correlations with the number of photographs, possibly because of the small number of culverts.

The present study employed temporary wooden ledges. As a result of the positive findings in this study, the testing of permanent retrofits is recommended. Such ledge retrofits are simple, easy, and inexpensive ($17 to $20 per linear foot plus shipping and installation). They could be developed locally, which would eliminate transportation costs. Recommendations resulting from the current study can be summarized as follows: 1) expand the study to additional culverts and continue use of ledges in the most active culverts of the present study, especially in *Z. h. preblei* habitat, to better determine factors affecting use by Preble’s, 2) develop an appropriate permanent ledge retrofit design locally, or consider installation of pre-built steel ledges and test their utility in Colorado, and 3) proactively begin discussions with the Colorado Department of Transportation engineers for construction/installation of new culverts that contain built-in ledges.

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EFFECTIVENESS OF LEDGES IN CULVERTS FOR SMALL MAMMAL PASSAGE

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Executive Summary

Transportation corridors present a number of problems for wildlife that live in their vicinity or that require crossings for dispersal or migration. One of the ecological impacts of roads is an increase in fragmentation of small mammal habitat and populations. Preble's meadow jumping mouse (*Zapus hudsonius preblei*), a federally threatened species that occurs along the Front Range of Colorado, has experienced habitat fragmentation by roads including interstate highways. It is of particular value to search for solutions that can reduce this fragmentation and facilitate movement of small mammals under roadways.

Temporary ledges were installed in six culverts to investigate small mammal movement under roads. Small mammal ledge use was measured by recording mammal passage with motion-detecting cameras. Ledges were connected to the streambank with removable ramps in order to test whether there was more usage when the ramps were on (ledges accessible) than when they were off (ledges inaccessible). The study tested whether Preble's meadow jumping mouse made use of the ledges, and whether they and other small mammals used the ledges more when they were accessible.

A total of 12 mammal species were photographed or observed using the culverts (including the culvert bottom) during the study spanning two summers, 2005 and 2006. Nine species used the installed ledges as documented in 705 photographs of small mammals on the ledge. *Z. h. preblei* individuals were photographed on the ledge once during the pilot and three times during the active study. There were 443 photographs of mammals on the ledge when the ramps were on and 262 photographs when the ramps were off. Both an analysis-of-variance and a nonparametric Kruskal-Wallis test were used to determine whether there was an effect due to differences in culverts and to whether the ramps were on or off over the ten two-week time periods of the two-year study. Significant differences among culverts and between ramp conditions were found

by both types of analyses. In addition to utilizing the ledges with the ramps on, the ledges present desirable passageways even with the ramps off, to the extent that small mammals will clamber their way up concrete walls to access them. Culvert dimensions and vegetative cover did not show statistical correlations with the number of mammals on the ledge, possibly because of the small number of culverts (six).

This study employed temporary wooden ledges. As a result of the positive findings, the implementation of permanent retrofit ledges, at $17 to $20 per linear foot plus installation, is strongly encouraged. A permanent retrofit ledge design can be developed in Colorado, and involvement of Colorado Department of Transportation (CDOT) engineers is strongly encouraged. The development of culverts with built-in ledges, as used in Europe, is also encouraged.

Implementation Statement

The present study tests the concept of temporary wooden ledges in culverts that will not withstand long-term use. The testing of permanent retrofits made of a durable material such as metal is recommended. Roscoe Steel and Culvert Company in Montana has developed permanent retrofit installations for sale (www.roscoebridge.com). They have installed these retrofits in 11 culverts in Montana on Highway 93. The ledge retrofits are simple, easy, and inexpensive ($17 to $20 per linear foot plus shipping and installation). Such retrofits could be developed locally, which would eliminate the transportation costs for shipping steel ledges from Montana to Colorado.

Other than this recommended materials specification change, the design, general construction, testing, and methodology components appear to have worked very well. No anticipated changes are recommended in these factors. A change is recommended in terms of the number of culverts used. The current study used only six.

The current study demonstrates that ledges are readily used by small mammals; however, the data are equivocal on use by Preble's meadow jumping mouse. Further testing with larger sample sizes (more culverts) can serve to better determine whether Preble's will use the ledges on a regular basis. An excellent opportunity to test permanent retrofit ledges has recently been provided by a Biological Opinion from the U.S. Fish and Wildlife Service (USFWS), dated December 28, 2006. In this letter, addressed to Larry Svoboda of the U.S. Environmental Protection Agency, USFWS has included the installation of four permanent ledges as a conservation measure for off-site mitigation for a wastewater treatment plant to be constructed in the town of Eldorado Springs, Boulder County, Colorado. Included in this project are four of the same ditches employed in the current study.

Ecoculverts, used in Europe, have raised dry ledges on each side of the water to allow for animal movement (Veenbaas and Brandjes 1999, cited in Forman et al. 2003). This is an excellent approach, and is highly recommended for consideration by CDOT.

The recommendations resulting from the current study can be summarized as follows:

- Expand the study to include additional culverts and continue the use of ledges in the most active culverts of the present study, especially in Preble's meadow jumping mouse habitat, to better determine factors affecting use by Preble's;

- Develop an appropriate permanent ledge retrofit design locally, or consider installation of Roscoe Steel ledges and test their utility in Colorado; and

- Proactively begin discussions with CDOT engineers for construction/installation of new culverts that contain built-in ledges.

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Introduction

Transportation corridors present a number of problems for wildlife that live in their vicinity or that require crossings for dispersal or migration. It has been estimated that approximately one-fifth of the U.S. land area is directly affected ecologically by the system of public roads (Forman 2000). Ecological impacts are due to loss of habitat patches; formation of barriers that isolate habitat patches and result in fragmentation; creation of disturbance due to noise, light, and air pollution; and road-kill mortality (van Bohemen 2004). The current study is focused on the problem caused by fragmentation to small mammal populations and presents one solution to this problem.

Populations of small mammals are fragmented by roads and highways that bisect the habitat and drainages along which they occur (Forman and Alexander 1998; Theobald et al. 1997; Trombulak and Frissell 2000). This may be due to dispersal abilities, low probability of surviving highway crossings, or behavioral avoidance of open highway expanses (Conrey and Mills 2001). Roads inhibit the movement of rodents (Clark et al. 2001; Kozel and Fleharty 1979) and affect their community structure and density (Adams and Geiss 1983). Preliminary results suggest that movement is hindered more by wider (four-lane) than narrower (two-lane) road crossings.

Species differ in their ability to negotiate roadway crossings: Red-backed voles (*Clethrionomys gapperi*) and chipmunks (*Neotamias* sp.) are inhibited more than deer mice (*Peromyscus maniculatus*) (Conrey and Mills 2001). Some species (prairie voles [*Microtus ochrogaster*] and cotton rats [*Sigmodon hispidus*]) are inhibited even on narrow dirt roads (Swihart and Slade 1984). In another study, very small percentages of white-footed mice (*P. leucopus*) and eastern chipmunks (*Tamias striatus*) crossed the roadway, suggesting that clearance distance between open habitats was a factor (Oxley et al. 1974).

Whereas these population fragmentation effects can occur in a relatively short time frame, genetic effects of fragmentation typically occur over a longer time frame, and have recently been demonstrated. Genetic differentiation occurred in European bank voles (*Clethrionomys glareolus*) on either side of a four-lane highway over only 25 years (Gerlach and Musolf 2000). These population and genetic effects of roadways present a significant problem to natural populations of small mammals. Because human populations continue to increase and require expansion of transportation routes through both new and wider roadways, it is of particular value to search for solutions that can safely facilitate movement of small mammals under roadways in order to reduce population and genetic fragmentation.

Passageways under highways via underpasses and drainage culverts were used by many native mammals in California (Ng et al. 2004). Barrier walls and culverts reduced roadkill in Florida from 2,411 to 158 in a 12-month period (Dodd et al. 2004). In Montana, the installation of ledges in culverts facilitated movement of 14 species of small mammals. Again, species differences were found: deer mice readily used ledges but meadow voles (*Microtus pennsylvanicus*) required a tube installed underneath the ledge which they used instead of the ledge (Foresman 2001, 2004).

The riparian-dwelling Preble's meadow jumping mouse (*Zapus hudsonius preblei*), a subspecies that is federally listed as threatened, may be substantially impacted where roads cross over drainages that they occupy. Populations of this mouse have been reduced, extirpated, and fragmented by development, grazing, gravel mining, and other activities. A Recovery Plan for the species was initiated (U.S. Department of Interior 2003), Critical Habitat has been determined, and efforts are underway all along the Colorado Front Range to conduct research on their populations (Meaney et al. 2002, 2003) and to develop plans to protect populations of this subspecies. However, in February 2005 the U.S. Fish and Wildlife Service (USFWS) issued a 12-month finding on a petition to delist the mouse. The decision on whether to delist the mouse has been postponed and is now anticipated in June 2007.

In Colorado Springs, Colorado, the construction of a large (65-meter [m]-long) culvert along Pine Creek at an I-25 exit may have fragmented a population of *Z. h. preblei*. At that site, animals were successfully trapped in June and August for 4 consecutive years on both ends of a newly installed culvert. Although the animals were permanently marked, there was no evidence of jumping mice passing from one end of the culvert to the other (Meaney and Ruggles 2000). Other drainages occupied by *Z. h. preblei* also flow into Monument Creek, which contains the largest population of the subspecies in El Paso County. All these tributaries are bisected by I-25. Roads can cause small populations to become fragmented due to reduced connectivity with adjacent subpopulations (Carr et al. 2002). These smaller subpopulations are at greater risk of extirpation than are larger interconnected populations.

The installation of ledges in culverts could mitigate this fragmentation effect. At another site, there is evidence from ongoing Colorado Department of Transportation (CDOT) research near the town of Monument and I-25 that Preble's meadow jumping mice do, at least occasionally, use culverts to cross under roads when there is a dry culvert section available. Both male and female adults and juveniles crossed through a 91-m-long concrete box culvert under I-25 along Dirty Woman Creek (Ensight 1999). Artificial cover stations were used to facilitate culvert usage, and jumping mice were found to cross through the culvert both with and without the cover stations. However, such movements were rare, with only five individually marked animals making the passage through the culvert over an eight-year period. Movements occurred during times of high and low water levels in the culvert; however, there was always at least some portion of the culvert bottom that was not inundated. Additional data from this drainage have shown that Preble's meadow jumping mice have moved under two-lane paved roads, presumably through corrugated metal culverts. Movement through the I-25 culvert may have been related to Preble's population density – in high-density years there was more movement, and in low-density years there was little detected movement.

Below-road passages are common in the landscape; many are designed for road runoff, drainage culverts, or movement of livestock and people. These passages are used by animals and can be important linkages and corridors for local wildlife. However, many could be used more effectively. Both transportation and natural resource agencies have overlooked these existing passages and their potential for improvement, even though substantial gains can be realized with relatively little investment (Forman et al. 2003).

The purpose of this study is to determine whether the installation of ledges in culverts containing water will facilitate the movement of small mammals, including *Z. h. preblei*, from one side to the other. The null and alternative hypotheses are:

Ho: Preble's meadow jumping mouse will not use ledges installed in culverts.

H_A: Preble's meadow jumping mouse will use ledges installed in culverts.

Ho: Small mammals will show no difference in their use of ledges with access to ledges (access ramps on) versus no access to ledges (access ramps off).

H_A: Small mammals will show a greater use of culverts with access to ledges than without access to ledges.

Methods

A list was compiled of all culverts in Boulder County, Colorado, that were within 10 kilometers (km) of known or potential populations of *Z. h. preblei*. The assumption was made that habitat suitable for this species would also provide habitat for numerous other small mammal species, as years of trapping surveys have indicated. Researchers located and examined 48 culverts. Culverts were eliminated from consideration for the following reasons:

- Permission from the ditch company or adjacent private landowner to install ledges was denied.

- There was more than one culvert opening and often one of the openings was dry, allowing easy passage without a ledge.

- The culvert was too small to fit a person and a ledge (typically less than 1 m in height or width or both).

- The culvert did not contain running water for at least two months or clearly had dry banks for a substantial portion of the season, as was the case for bridges over streams.

- The water current and depth were deemed too dangerous for working inside the culvert.

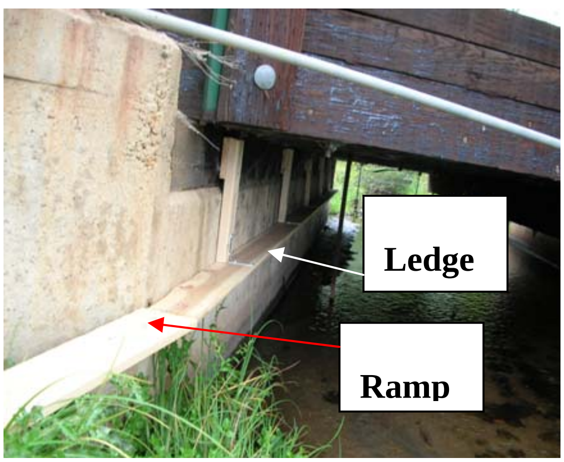
- Extensive barn swallow (*Hirundo rustica*) or cliff swallow (*Petrochelidon pyrrhonota*) nests were present.

- The culvert was gated and access was denied.

- The high-water mark suggested the ledge would be flooded during the active season.

- Excessive development in the vicinity of the culvert existed.

This process of elimination resulted in seven culverts deemed suitable for the project. One of these culverts was subsequently rejected. The six remaining culverts were outfitted with wooden ledges (2.54 x 15.24-centimeter [cm] cedar planks, typically 1.83 m long) attached end to end. We glued blocks of wood (5 x 10.16-cm blocks, 30.48 cm long) to the culvert wall above the high-water line at 1.83-m intervals with Liquid Nails glue applied with a caulk gun. These served as anchors for the ledge planks, which were placed on top and screwed into the blocks.



Ramps, also made of 2.54 x 15.24-cm cedar planks, were outfitted with hinges and attached to the end of the ledge. They were angle-cut to provide the best horizontal angle to reach the bank, and the hinge allowed for the best vertical angle, so that they provided access from solid ground along the bank to the ledge. During the first year of the study, the access ramps were taken on and off as a means to make the ledges accessible and inaccessible, respectively. This was far more cost-effective than removing and replacing the entire ledge for the 2-week time intervals that defined each sample period. During the second year, both the ramp and first board of the ledge were removed at both ends of the culvert.

Goodhue Ditch at U.S. 36. Ramp is long and vegetation is well-developed; ledge not visible inside culvert. Note green netting for birds.

Small mammal movements through the culverts were assessed with photographs. Still cameras were purchased from TrailMaster (Goodson & Associates, Inc., Lenexa, Kansas). We employed the TM 550 monitor and motion-sensitive camera setup, a passive sensing unit that detects infrared waves and microwaves (for temperature differential and movement, respectively). Monitors recorded all interruption incidents of the cone-shaped beam. Motion-sensitive cameras allowed for remote sensing of animals by photographs taken when criteria were met to trigger the camera.

Camera (left) and monitor (right) installation. They are placed on a metal platform attached to the culvert wall.

The cameras were attached to the culvert with the use of 5 x 10.16-cm wooden blocks glued to the sidewall. One culvert required suspension of the camera unit from the culvert ceiling because of its width, and one had a wood beam running through the center that allowed for direct attachment. Metal L-shaped plates were built and used to provide a platform to accommodate the camera and monitor as well as a vertical component for attachment to the culvert.

Cameras and monitors were extensively field-tested for two months prior to the initiation of the experiment, as settings and angles require much adjusting. The units were placed in the middle of the culvert, except in Culvert 4 and Culvert 7 due to the small opening or fast-running (and therefore dangerous) water. This positioning served to avoid photographing animals that may have entered and turned around, rather than passing all the way through. Cameras were angled to focus on the ledge. We had hoped to angle the cameras to pick up the bottom of the culvert as well; however, this was not possible in most cases. Cameras and monitors were checked weekly and film was replaced as needed. We employed 200 ASA Fuji film with 24 or 36 exposures.

The experiment ran from June 1 through September 21, 2005 (16 weeks), and from May 2 through September 19, 2006 (20 weeks). Ten two-week periods were defined in 2006 and eight such periods were employed in 2005. A given culvert alternated between having ramps on for two weeks and ramps off for two weeks, generally within each month of the summer season. Each culvert was randomly assigned to the ramp on or off condition for the first period with subsequent alternating conditions per period.

Culvert dimensions (length, width, and height) were measured and water depth was noted weekly in 2005. Vegetative cover was assessed at each culvert entrance in 2005. Three adjacent vegetation sampling quadrats were established immediately upstream and downstream of each culvert. One 5 x 5-m quadrat was situated on each bank and a third quadrat was defined as the area between the two bank quadrats and centered on the culvert. Within each quadrat the percent foliar cover (to the nearest 5 percent) of tree, shrub, forb, and graminoid species was recorded. Regression analysis was used to assess the relationship of these parameters with the number of photographs of small mammals on the ledge.

The study employed a multifactor analysis of variance (ANOVA) (MANOVA) on the number of photographs of mammals on the ledges during the 10 periods, as well as various regression analyses on culvert dimensions, vegetation, and water levels. For the MANOVA, we tested the significance of two factors: the ledges with ramps (on or off), and culvert. The dependent variable (number of mammals photographed on the ledge) was square root transformed. When assumptions of the ANOVA test could not be met, the Kruskal-Wallis test was employed. This test does not require normally distributed data and tolerates heterogeneous variance.

Small mammals were identified from photographs by their color, relative tail length, body carriage, and shape. Familiarity with these species from small mammal trapping in the region facilitated identifications. Shrews were identified only to genus (as *Sorex* sp.).

Results

The seven originally selected culverts are listed in Table A and shown on Figure 1. Photographs of all the culverts, located in Boulder, Colorado, are provided in Appendix A. Culvert 6 (South Branch) was eliminated from the study, leaving a sample size of six, because it was discovered that vehicles driving over the road caused vibrations that triggered the monitor and camera. Although 530 photographs were taken in both years at this culvert, only two were of mammals on the ledge and the remainder were blank.

Table A. Culverts used in the study

Culvert	Location	Culvert Type[1]	Culvert Dimension (m) Width x Height	Culvert Length (m)
Culvert 1 Dry Creek No. 2 Ditch	US 36	CBC	1.9 x 1.25	47.5
Culvert 2 Marshallville Ditch	US 36	CBC	2.4 x 1.3	46.8
Culvert 3 Goodhue Ditch	US 36	CBC	4.9 x 1.2	47
Culvert 4 East Boulder Ditch	Cherryvale Road	RCC	1 x 1	38.7
Culvert 5 Marshallville Ditch	Marshall Road	CBC	1.85 x 0.9	9
Culvert 6[2] South Branch	Crane Hollow Road	Timber bridge with concrete sidewalls	3.8 x 1.2	8.6
Culvert 7 Davidson Ditch	SH 170 (Eldorado Springs Road)	CBC	3.7 x 1.2	27.2

Notes:
[1]CBC = concrete box culvert; RCC = round concrete culvert
Ramp lengths ranged from 1.0 to 3.95 m, and the mean length was 2.34 m.
[2]Culvert 6 was rejected due to vibrations from cars that triggered the monitor and camera.

Figure 1. Locations of six culverts with ledges in Boulder, Colorado

A total of 12 mammal species were photographed or observed using the culverts (on the ledge, on the wall, or on the bottom of the culvert) and nine species were photographed using the ledge during the entire project (Table B). Five species of birds were captured by the camera flying around and sitting on the ledge, as well as numerous spiders and a few dragonflies.

Table B. Species observed using culverts during the project

Common Name	Scientific Name	On Ledge?
Mammals		
Shrew	*Sorex* sp.	Yes
Rock squirrel	*Spermophilus variegatus*	Yes
Black-tailed prairie dog	*Cynomys ludovicianus*	No
Deer mouse	*Peromyscus maniculatus*	Yes
Mexican woodrat	*Neotoma mexicana*	Yes
Norway rat	*Rattus norvegicus*	Yes
House mouse	*Mus musculus*	Yes
Meadow vole	*Microtus pennsylvanicus*	Yes
Preble’s meadow jumping mouse	*Zapus hudsonius preblei*	Yes
Coyote	*Canis latrans*	No
Raccoon	*Procyon lotor*	Yes
Striped skunk	*Mephitis mephitis*	No
Birds		
Barn swallow	*Hirundo rustica*	NA
Song sparrow	*Melospiza melodia*	NA
Brewer’s blackbird	*Euphagus cyanocephalus*	NA
Belted kingfisher	*Ceryle alcyon*	NA
Great blue heron	*Ardea herodias*	NA
Invertebrates		
Spider	-	NA
Dragonfly	-	NA

A total of 3,830 events were recorded by the monitors (the beam was triggered by a movement event) and 2,105 photographs were taken in the six culverts during the 16- and 18-week study over two seasons. Of these, 906 were photographs of animals; the remainder were blank indicating that the monitor was triggered but the camera did not capture anything. Of these 906 animal photographs, 722 were of mammals. Of these, 705 were photographs of mammals on the ledges (Figure 2). Many photographs were triggered by birds flying in and out, and by spiders.

Deer mouse on ledge.

Mexican woodrat at Davidson Ditch.

Preble's meadow jumping mouse at Goodhue Ditch during pilot portion of study.

Meadow vole at Davidson Ditch.

House mouse at Marshallville Ditch at Marshall Road.

Figure 2. Photographs of various mammal species captured by remote-sensing cameras in culverts

There were more photographs of mammals on the ledges when the ramps were on (443 photographs) versus when they were off (262 photographs) (Figure 3).

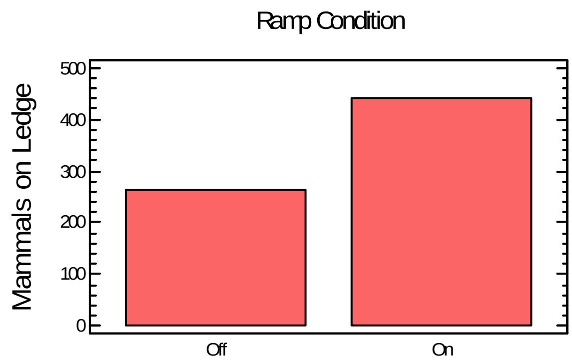


Figure 3. Number of photographs of mammals on the ledges with ramps on and off

The question of interest was whether there was a significant difference in the number of mammals photographed on the ledge with the ramp on or off. The other factor of note was the culvert. There were differences among the culverts in their dimensions, the vegetation at their entrance, and the small mammal communities in the ditches that passed through the culverts. A MANOVA was used to test the effect of the ramp (were there more photographed mammals when the ramps were on versus off?) and culvert (were there differences in the number of photographed mammals among the different culverts?). The data set was skewed, with most small mammal species showing low to modest movement numbers, and deer mice typically having values 10 to 50 times that of the other species.

To better approximate a normal distribution, and to render the discrete data continuous, the dependent variable (number of mammals on ledge) was square root transformed for the MANOVA. There were significant effects of culvert and ramp on the number of mammals on the ledge ($F = 10.16$ and 9.08, $p = 0.0$ and 0.0034 for culvert and ramp, respectively). The interaction between the two factors was not significant ($F = 0.15$, $p =$

0.9802). However, the data did not meet the assumptions of normality of residuals and equality of variances, and the nonparametric Kruskal-Wallis test was employed. The Kruskal-Wallis test showed significant differences between culverts (H = 29.384, p = 0.000) and between ramp conditions (H = 7.356, p = 0.0067).

Figure 4 shows the differences among the culverts and ramp conditions. Culvert 3, Goodhue Ditch, had the greatest amount of overall activity. Culverts 1, 2, and 7 had medium activity, and Culverts 4 and 5 had the least. Culverts 1, 2, and 3 crossed under US 36, a four-lane highway with a jersey (concrete highway) barrier. Culvert 4 was very small, with a 1-m-diameter opening, and Culvert 5 was under a very small two-lane road in a quiet, rural residential area.

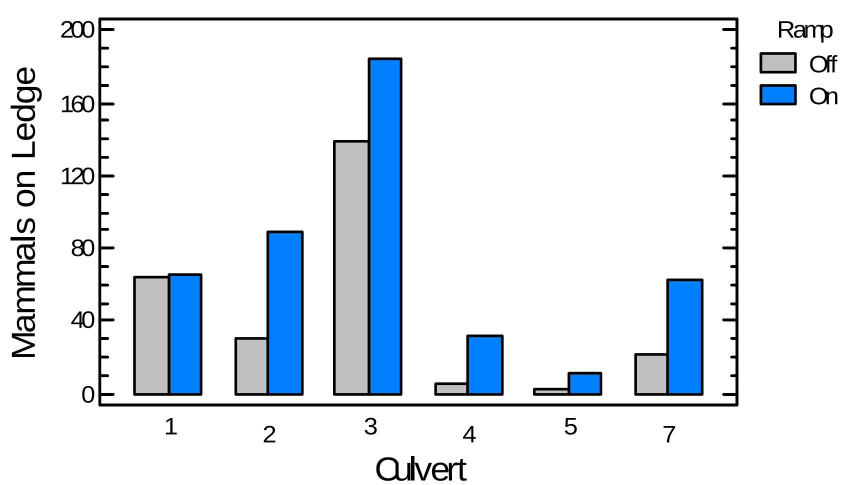


Figure 4. Number of photographs of mammals on the ledges at six different culverts

In addition to differences in the amount of activity at the different culverts, there were also differences in small mammal species richness. Although Culvert 3 had the greatest amount of activity, the activity was due to a high number of deer mice. Culverts 1 and 3 had the lowest species richness, with only three species each. Culverts 4 and 5, with low overall activity, had the highest richness with five species each. Culvert 2 was relatively high or intermediate on both measures, with a high overall activity level and four species (Figure 5).

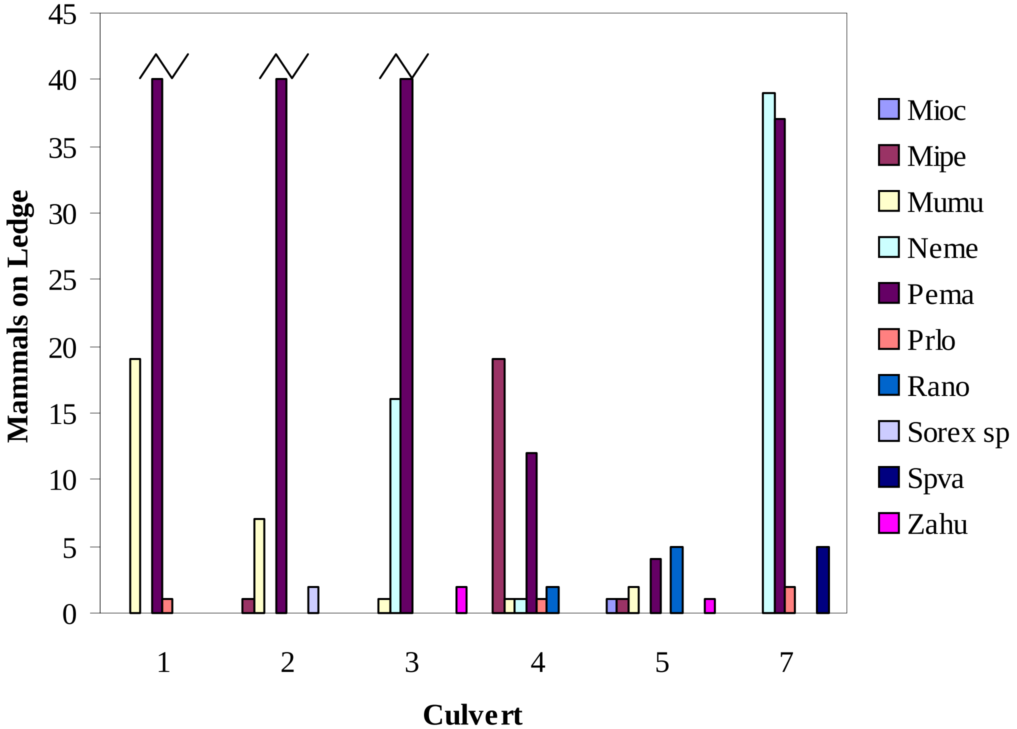


Figure 5. Species richness of small mammals photographed at six culverts Mioc=prairie vole, Mipe=meadow vole, Mumu=house mouse, Neme=Mexican woodrat, Pema=deer mouse, Prlo=raccoon, Rano=Norway rat, Sorex sp=shrew, Spva=rock squirrel, Zahu=Preble's meadow jumping mouse

Notes:

indicates a break in the range for PEMA values

Culvert 1 PEMA = 110 animals
Culvert 2 PEMA = 109 animals
Culvert 3 PEMA = 304 animals

It is noteworthy that small mammals did access ledges when the ramps were off (Figures 3 and 4). However, all six culverts had more activity when the ramps were on than with the ramps off. The distances that small mammals negotiated from the streambank (solid ground) to the ramp ranged from 39 to 78 cm and the distance from the ramp to the top of the culvert ranged from 20 to 80 cm; for those ledges that ended above water rather than solid ground, the lateral distance was 42 to 148 cm. Culvert 1 (Dry Creek No. 2 Ditch) was one of the two culverts with high activity without the ramp and is shown below.

End of ledge at Dry Creek No. 2 Ditch culvert at U.S. 36. Note hinge to connect ramp. Distance from ledge to ground is 54 cm. Bird netting is visible.

In 2006, the study ran for an extra month because it was started in May to capture potential early season activity, as occurred during the pilot in 2005. With this larger data set, we looked at the potential difference in use of ledges with ramps off and on. The results suggest a small difference, with 87 and 109 animals in 2005 and 174 and 333 animals in 2006 with the ramps off and on, respectively (Figure 6). These differences represent 11 percent and 31 percent of the total for 2005 and 2006, respectively.

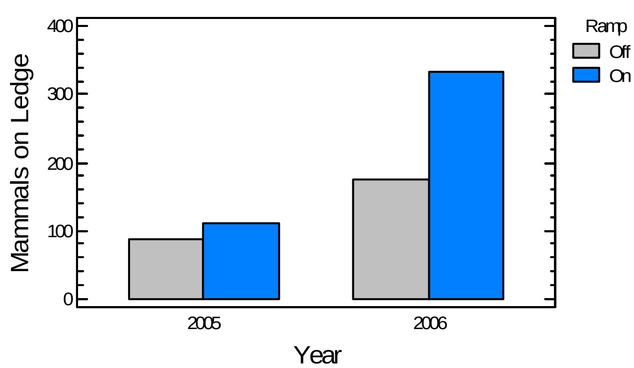


Figure 6. Number of photographs of mammals on the ledges with ramps on and off in 2005 and 2006

We evaluated whether certain species had a better ability to access the ledges with the ramps off (Figure 7). All species accessed the ledges more frequently when the ramp was on than when it was off. The prairie vole, shrew, and Preble's meadow jumping mouse did not access the ledges when the ramps were off, but they also used the ledges infrequently altogether. Small mammals, and deer mice in particular with their overall high level of activity, clearly have the ability to walk on the vertical concrete wall.

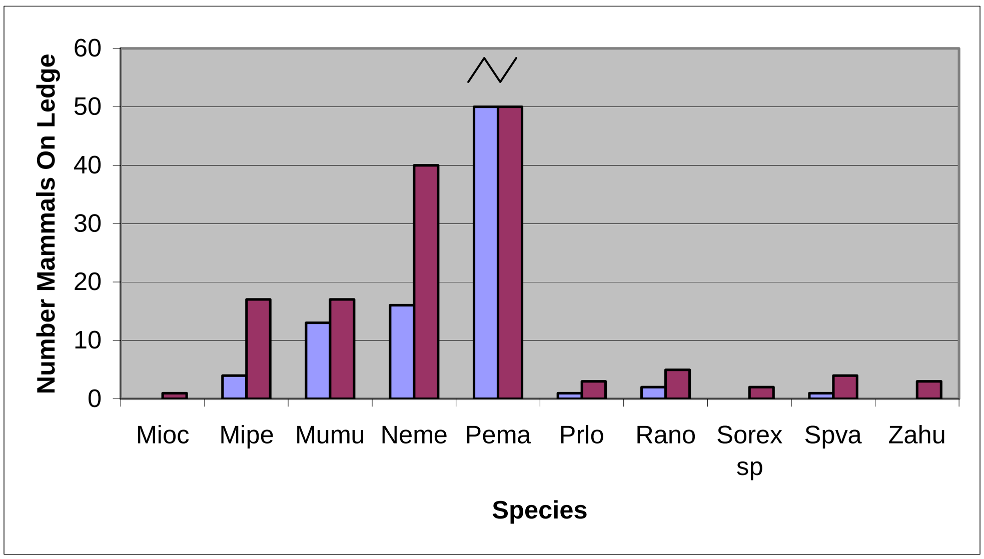


Figure 7. Mammal species on the ledges with the ramps on and off Mioc=prairie vole, Mipe=meadow vole, Mumu=house mouse, Neme=Mexican woodrat, Pema=deer mouse, Prlo=raccoon, Rano=Norway rat, Sorex sp=shrew, Spva=rock squirrel, Zahu=Preble's meadow jumping mouse

Notes:
/\/ *indicates a break in the range for PEMA values*
PEMA ramp on = 351
PEMA ramp off = 225

The mammal-on-ledge activity showed some variation and some overall consistency across periods (Figure 8). The highest activity occurred during Periods 3 through 8, June through August.

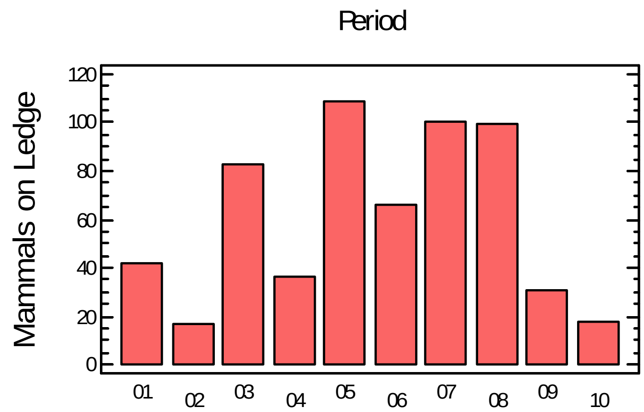


Figure 8. Number of photographs of mammals on the ledges in the ten periods from June through September 2005, and May through September 2006

We evaluated the culvert dimensions (length, height, and width). Length of the culvert was assumed to address potential differences in use by small mammals between shorter (two-lane road) and longer (four-lane road) culverts. Simple regression analysis showed no significant correlation at the $\alpha = 0.05$ level between the total number of mammals photographed on the ledge for each culvert and its length ($r_s = 0.74$, $p = 0.0958$, $n = 6$), width ($r_s = 0.78$, $p = 0.0699$), or height ($r_s = 0.72$, $p = 0.1053$), although the correlations were high.

We evaluated the potential correlation of vegetation at the entrances to the culverts and the mammal activity on the ledge. We combined percent cover for all six plots at each culvert (three on the upstream end and three on the downstream end) across all four plant cover types to determine a total foliar cover value (total foliar cover = tree + shrub + forb + grass cover). There was no significant correlation in the number of mammals on the ledge with percent cover ($r_s = 0.171$, $p = 0.7454$, $n = 6$).

Four photographs captured Preble's meadow jumping mouse using the ledges. The first photograph was taken during the pilot portion of the study in May 2005, on Goodhue

Ditch (Culvert 3) under U.S. 36 (Figure 2). Because of the animal photographed in May 2005, the study was started earlier in 2006 (at the beginning of May). Goodhue Ditch provided excellent habitat, had high overall use of the ledge and low species richness, and was dominated by deer mice. The second photograph was taken July 21, 2005, on Marshallville Ditch at Marshall Road (Culvert 5), under a small two-lane road in a rural residential area where overall activity was low and species richness was high. The third and fourth photographs were from Goodhue Ditch, taken May 28 and June 16, 2006, respectively (Figure 9).

Figure 9. Three events of Preble's meadow jumping mice on ledges photographed during the study

Note: Clockwise from upper left: July 21, 2005 at Culvert 5; May 28, 2006 at Culvert 3; and June 16, 2006 at Culvert 3.

Discussion

The results of this study show that ledges installed in culverts containing water are readily used by small mammals as evidenced by 705 photographs documenting small mammal passage on ledges in six culverts. Furthermore, these culvert ledges are employed by a broad range of species, including nine species of mammals documented in this study. Culverts, and more notably culverts with ledges, serve as valuable passageways in an environment fragmented by roads.

Both the presence or absence of ledges in culverts, and the differences among the six culverts, significantly affected the number of small mammals that passed through the culverts ($\alpha = 0.05$). The culverts were inherently different in type, style, length, and width. It is likely that certain ditches had higher abundances of small mammals than did others, and thus some culverts would receive more use as a consequence. In addition, some of the culverts were frequented by spiders building webs and birds flying in and out, both of which tripped the cameras and likely precluded capturing small mammals on film. During the second year, mesh netting was reinforced on the culvert entrances to prevent use by birds. The higher mammal activity level in 2006 may have been a result.

Culvert 3, on Goodhue Ditch at U.S. 36, had the greatest amount of activity (Figure 4). Goodhue Ditch provides excellent habitat, with lush vegetation along its banks. It also is a culvert in which it is possible to see end-to-end. Even at night, this may present a detectible difference. East Boulder Ditch (Culvert 4) is dark, Marshallville Ditch at U.S. 36 (Culvert 2) is dark and has a bend in it, and Davidson Ditch (Culvert 7) has a bend in it. None of the small mammal species documented in the photographs are strictly fossorial, and the degree of ambient light may be a factor in the use of culverts.

The assumption was made that the ramps were necessary to access the ledges. Interestingly, this was not the case because small mammals accessed the ledges even when the ramps were off. However, all culverts as well as species showed more use of the ledges with the ramps on. Small mammals appear to have an ability to climb vertical concrete walls. Whether the animals climbed down onto the ledge from above (20 to 80 cm) or climbed up to it from the closest point along the bank (39 to 78 cm) is not known. A few photographs captured animals on the concrete wall of the culvert including a shrew and a deer mouse that was trying to reach a cliff swallow nest above the ledge. It appears that the ledge was of such utility to these small mammals that they made reasonable efforts to get to it.

Deer mouse climbing concrete wall toward a cliff swallow nest.

Twelve species of mammals used the culverts in the present study, which was comparable to use in a study in Montana where 14 species were documented using six culverts (Foresman 2004). In that study, 14 species also employed the ledges, whereas only nine species were observed to use the ledges in the current study (Table B). The Montana study also found differences in use by species, with deer mice readily using the ledges but voles avoiding them, whereas meadow voles used the ledges in the present study. The Montana study used ledges constructed of metal grating with a solid metal edge. Mice always used the solid metal edge, and perhaps voles had no tolerance for the grating substrate. In the Montana study, tubes were installed (similar to gutter drain pipes) under the ledges, which facilitated use by voles.

The present study documented use by Preble's meadow jumping mouse once during the pilot (May 2005) and three times during the study in May, June, and July in two culverts. The six culverts were selected for their proximity to South Boulder Creek, habitat for the main population of Preble's meadow jumping mouse in Boulder County (Meaney et al. 2002, 2003). East Boulder Ditch is also known to be occupied, with densities of 34 to 86 animals per km along the ditch in the stretch immediately adjacent to Culvert 4. That culvert has the smallest opening of all the culverts, 1 m in diameter, and a length of 38 m. It is possible that the narrower opening affected the lack of use by Preble's meadow jumping mouse. However, the East Boulder Ditch culvert had relatively low use overall, albeit a high species richness (Figures 4 and 5). Davidson Ditch (Culvert 7) is within approximately 50 m of a known population of Preble's meadow jumping mice along South Boulder Creek; however, none were photographed. Goodhue Ditch (Culvert 3), with three Preble's meadow jumping mice, was noteworthy for having the greatest overall activity (Figure 4) and excellent habitat, albeit low species richness (Figure 5). Marshallville Ditch at Marshall Road (Culvert 5), also with one photograph of Preble's, is a very short culvert in a rural residential neighborhood with a section of mowed lawn adjacent to the ditch. It had low overall use and high species richness.

It is interesting that the level of activity, measured mostly by deer mice, appeared inversely correlated with species richness. That is not necessarily typical for small mammal trapping efforts. Across the 10 periods, activity was generally consistent with highest activity during the middle of the summer. The increase is likely due to the addition of the year's young. The decline in September may be due to reductions in water levels such that animals may have had some access to dry banks to pass through the culverts without using the ledges.

A number of studies have found a relationship between culvert use and characteristics such as culvert dimension. In Spain, length of the culvert was negatively correlated with a crossing index for small mammals, whereas height, width, and openness were positively correlated with the crossing index, which was determined solely from track plates in and near the culvert (Yanes et al. 1995). The lack of correlation between small mammal photographs and culvert dimensions in the present study may be due to a small sample size of six culverts, in comparison with the Spanish study, which had a sample of 17 culverts (Yanes et al. 1995). Another study, using sooted track plates, found a negative correlation between culvert use and road width for two of five taxa (coyotes [*Canis latrans*] and red squirrels [*Tamiasciurus hudsonicus*]). Small mammals such as mice, although the most common culvert users, had been removed from subsequent analyses because their tracks did not show up on track plates adjacent to the culverts (Clevenger et al. 2001). In another study, landscape variables were important in determining the probability and frequency of underpass use, whereas dimension variables were more important in determining the frequency of use (Haas and Crooks 2001).

Another factor that is generally found to relate directly with culvert use is vegetative cover and/or height. In Montana, use of culverts increased with percent cover and height of vegetation, although no statistical analyses were conducted on the six culverts employed in that study (Foresman 2004). The present study did not show that relationship, and it is suspected that the small number of culverts is a factor.

Mammals have an excellent ability to learn. This is significant to the present study because animals had to learn to use the ledges. For example, it is likely that if a mouse accessed a ledge when the ramps were on, it would then have a greater motivation to access the ledge when the “ramps off” condition was encountered, having previously learned the utility of this new passageway. However, it is not known whether all the photographs taken with ramps off were animals that had previously accessed the ledges when the ramps were on. Because animals were not marked, it also is not known how many times a particular individual made use of the ledges, or how many different individual mammals made use of the ledges.

Preble's meadow jumping mouse is a long-lived small mammal. Whereas deer mice seldom live one year, Preble's can live three or four years (Meaney et al. 2002). This longevity allows for learning to occur. Furthermore, Preble's are known to travel great distances. They are excellent dispersers and travel from summering areas to hibernation sites. These factors combined (i.e., relative longevity and high vagility) suggest a potential utility of ledges in culverts for Preble's. However, given that only 3 of the 705 photographs taken during the study documented use by Preble's, they used the ledges infrequently. And although long-lived, the majority of individuals will not make it through one active season. Alternately, if Preble's are typically 5 percent of the local small mammal population, and they use the ledges as readily as the other small mammals that use them, there should have been approximately 35 Preble's meadow jumping mouse photos out of the 705 total. However, even if Preble's movements on ledges are rare, there still may be tangible benefits of a few animals moving from one side of a culvert to another, allowing connectivity among adjacent populations. And given the low cost for installation of permanent ledges, this is a very good value and well worth the effort.

In Australia, a rare small mammal, the mountain pygmy-possum (*Burramys parvus*), was experiencing population declines due to fragmentation of its habitat by roads and other development. By constructing tunnels containing rocks to imitate this marsupial's habitat (talus), natural movements were restored and population and survival rates increased (Mansergh and Scotts 1989, cited in Forman et al. 2003). There is the opportunity for a similar degree of success with Preble's meadow jumping mouse.

A telephone survey to evaluate the use and effectiveness of wildlife crossings revealed that, as of September 2005, there were at least 460 terrestrial and 300 aquatic crossings in North America. New roads are being planned and constructed with permeability to wildlife as part of the process (Cramer and Bissonette 2005). Mitigation measures designed to lessen the impact of roads on wildlife are a necessary and significant component of a sustainable transportation strategy and, although various techniques are being employed, there is an urgent need for rigorous evaluation of these measures and for the development and testing of new ones (Forman et al. 2003).

This is an important area of research and will provide “win-win” solutions for the enhanced mobility of wildlife in the face of growing transportation corridors. Studies are currently underway to determine how best to proceed with new roadways with considerations for animal migrations and movement, underpass/overpass locations, and construction details (Brodziewska 2005). The present study reveals the utility of retrofitting existing structures for small mammal passage through culverts and a small but inexpensive benefit for Preble’s meadow jumping mice.

Conclusions and Recommendations

This two-year study is the first study to our knowledge that applies an experimental procedure to evaluate the utility to small mammals of ledges installed in culverts. This appears to offer a significant and inexpensive means for increasing the permeability of roadways to small mammals. This research project demonstrates that small mammals readily make use of ledges in water-filled culverts to pass under roadways.

The testing of permanent retrofits is recommended. The present study tests the concept with materials that will not withstand long-term use. Roscoe Steel and Culvert Company in Montana sells permanent retrofit ledges (www.roscoebridge.com). The recommendation is to implement a working process with CDOT engineers and staff to assess the potential use of this retrofit equipment in Colorado, and to test its effectiveness. It was discovered that the ledge construction used in the Montana study (metal grating with 1-inch-wide diamond-shaped openings) was not optimal because the lattice openings were too large for small mammals. The final design used #13 flat galvanized expanded metal mesh (Foresman 2004). These types of engineering details are significant and require field-testing in Colorado to maximize the benefits. It may also be more cost-effective to find a local source for permanent retrofit ledges in Colorado. A further step recommended for implementation is the development and construction of culverts with pre-installed ledges. These can be directly formed in the concrete.

Another option includes using multiple-cell culverts that are built under roads. One cell serves as a low-flow channel, and generally conducts water during the growing season. The other cell(s) are built at a higher grade, and remain dry except during storm events. The latter cells can be used by small mammals for passage.

The study of transportation and wildlife is a relatively new field. Much has been learned, and much remains to be understood. The presence of roads has negative impacts on many animals for a variety of reasons and culverts appear to have general positive impact on animal movement. The use of ledges in culverts that contain water is clearly demonstrated in the present study to facilitate movement by many species of small mammals. The main recommendation pursuant to the present study is to initiate a program to install permanent ledges in culverts where Preble's populations are bisected by roads. Although the number of Preble's meadow jumping mice using the ledges was small, the authors feel that Preble's have great potential to use these ledges given time and sufficient exposure to them. In summary, the recommendations for Colorado are:

- Expand the study to additional culverts and continue use of ledges in the most active culverts of the present study, especially in Preble's meadow jumping mouse habitat, to better determine factors affecting use by Preble's;

- Develop an appropriate permanent ledge retrofit design locally, or consider installation of Roscoe Steel ledges and test their utility in Colorado; and

- Proactively begin discussions with CDOT engineers for construction/installation of new culverts that contain built-in ledges.

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Appendix A: Photographs of the Culverts Used in the Study.

Culvert 1. Dry Creek Ditch No. 2 at U.S. 36.

Culvert 2. Marshallville at U.S. 36.

Culvert 3. Goodhue Ditch at U.S. 36. Bird netting visible.

Culvert 4. East Boulder Ditch. This is a round concrete culvert and the smallest diameter (1 m) of all the culverts.

Culvert 5. Marshallville Ditch at Marshall Road. Both ledge and ramp visible at right; note strap hinge to connect them.

Culvert 6. South Branch of St. Vrain Creek at Crane Hollow Road. This culvert was eliminated from the study (see text). Ledge is inside culvert, ramp is on wing wall.

Culvert 7. Davidson Ditch at State Highway 170 in Eldorado Springs.