Peer Reviewed

Potential Effects of Livestock Water-Trough Modifications on Bats in Northern Arizona

STUART R. TUTTLE,[1,2] *Department of Biological Sciences, Northern Arizona University, Flagstaff, AZ 86011, USA*
CAROL L. CHAMBERS, *School of Forestry, Northern Arizona University, Flagstaff, AZ 86011, USA*
TAD C. THEIMER, *Department of Biological Sciences, Northern Arizona University, Flagstaff AZ 86011, USA*

Abstract

In the southwestern United States, livestock water troughs may be the only water source available to bats during dry seasons or periods of drought. We found that 38% of the 90 livestock water troughs we surveyed in northern Arizona, USA, were modified with either fencing to separate pastures or braces to strengthen the structures. We tested if these modifications could affect bat drinking behavior or increase injury risk by simultaneously videotaping modified and unmodified troughs in a series of crossover experiments performed between 1 March and 26 August 2004. The bats that we observed did not avoid modified troughs but required 3–6 times the number of passes to approach the water surface at both troughs with fences and those with support braces. The number of passes required to drink increased with reduced water surface area, suggesting that modifications of smaller troughs may have a greater effect. Small (e.g., Myotis *spp.) and large (e.g., pallid bat [*Antrozous pallidus*]) bats responded similarly in the experiments. These effects may be energetically expensive for bats, especially during periods of high energy demands, such as pregnancy and lactation. Although we did not document any injuries or mortalities, 16 bats contacted wires at modified troughs with smaller surface area. This suggests that modifications of smaller troughs may pose higher risks of injury. To reduce these risks, we recommend removing modifications on water troughs whenever feasible.* (WILDLIFE SOCIETY BULLETIN 34(3):602–608; 2006)

Key words

Antrozous pallidus*, Arizona, energetic costs, fences, flight path,* Myotis*, pallid bat.*

Estimates of daily evaporative water loss in bats range as high as 30–50% of total body water (O'Farrell et al. 1971, Webb et al. 1995) and for big brown bats (*Eptesicus fuscus*) estimates of the percentage of total dietary water obtained from free water sources range from ~22% (Kurta et al. 1990) to 42% (Carpenter 1969), indicating at least some reliance on free water. Bats drink water by swooping over a water source and lapping at the surface (Harvey et al. 1999), but it is unknown how critical free water is for bat survival. Several studies demonstrated that diurnal roost sites tend to be closer to water sources than expected based on random locations, and foraging activity has been shown to be higher near water sources than farther away (Rabe et al. 1998, Waldien and Hayes 2001). Both relationships could be due to either dependence on free water or the greater prey abundance associated with water sources (Entwhistle et al. 1997, Rabe et al. 1998, Evelyn et al. 2004, but see Waldien et al. 2000).

Bats can potentially obtain water from natural sources that provide an open, unobstructed surface. In arid regions like the southwestern United States, artificial water sources may be the only water available, especially during periods of drought. In these areas, livestock water troughs (hereafter referred to as troughs) supplied by a permanent water development such as a well or spring, may be the most reliable year-round water source for bats. However, modifying troughs by placing wires, braces, or other structures above the water may either prevent access or require bats to make multiple approaches to access water. Troughs are modified in these ways to allow livestock access to water from 2 or more pastures, to prevent livestock from entering the trough, or to maintain trough stability.

Andrew et al. (2001) speculated that trough modifications, design, or water level could increase bat mortality. Bats not dying immediately from an impact with a modification or interior side of a trough may drown if an escape structure is not present that allows them to climb out of the water (Kolb 1984). Although it is unknown how many troughs exist in the southwest, some estimates have been in the tens of thousands (D. Taylor, Bat Conservation International, personal communication).

The Natural Resources Conservation Service (NRCS) documented the installation of 180 water facilities from 1997–2005 on nonfederal lands in 5 counties of northern Arizona, with 500 more planned for the same area by 2010 (NRCS, unpublished data). Given this potential for bat–trough interactions, it is important to understand how trough modifications may affect bat use and if they increase risk of mortality.

To conduct this study we surveyed troughs in northern Arizona to determine the most common types of trough configurations and modifications present. We used this information to design and implement a series of experiments to determine if the most common modifications affected bats. Specifically, we were interested in learning: 1) do fences across troughs alter access of bats to the water surface?, 2) does decreasing the water surface area affect bat behavior at fenced troughs?, 3) do support braces on rectangular troughs reduce access to water?, and 4) what is the potential for trough modifications to cause bat injury or mortality? Our methods did not allow us to identify bat species in these experiments, but we were able to determine if larger bats (e.g., those similar in size to the pallid bat [*Antrozous pallidus*], ~30 g) responded differently than smaller bats (those similar in size to *Myotis* spp., ~6–8 g).

Study Area

Between 1 March and 19 May 2004, we conducted an inventory of livestock water troughs across northern Arizona on federal and

[1] *E-mail: stu.tuttle@az.usda.gov*
[2] *Present address: Natural Resources Conservation Service, Flagstaff, AZ 86001, USA*

Figure 1. Experimental trough design at Raymond Wildlife Area, Arizona, USA, showing a modified circular and an unmodified rectangular trough (1 Jul 2004). Black and white video cameras and infrared lights are mounted on the pole between the troughs. The recording equipment is located 76 m away from the troughs.

state land and on private land when granted permission. Between 20 May and 26 August 2004, we conducted 4 experiments on the 6,070-ha Arizona Game and Fish Department's Raymond Ranch Wildlife Area approximately 60 km southeast of Flagstaff, Arizona, USA. The study site was located at 1,731-m elevation on the eastern edge of the wildlife area in Great Basin grassland (Brown 1994) consisting primarily of blue grama (*Bouteloua gracilis*), galleta (*Pleuraphis jamesii*), four-wing saltbush (*Atriplex canescens*), and snakeweed (*Gutierrezia sarothrae*). Two livestock tanks (ponds) were located 3 km from the study site and contained water until 1 June 2004. Other tanks and troughs were >6 km from the study site.

In addition to the experiments on the Raymond Wildlife Area, we conducted single-night experiments at 2 other sites, House Rock Wildlife Area (hereafter House Rock) on the north rim of the Grand Canyon (also managed by the Arizona Game and Fish Department) and at another site 19 km north of House Rock on Bureau of Land Management (BLM) land. Both sites were ~1,700-m elevation in Great Basin grassland with similar plant communities to Raymond. Additional water sources were located approximately 3 km away from each study site.

Methods

Trough Inventory

We collected data whenever we encountered troughs along public roads across northern Arizona and on 4 ranches in grassland, desert scrub, and pinyon–juniper woodland (*Pinus edulis–Juniperus osteosperma*) vegetation types from ~1,400-m to ~1,800-m elevation. For each trough we measured dimensions (height, diameter for round, or width and length for rectangular troughs) and recorded whether modifications were present. Modifications were classified as "wire fence" (≥1 strands of barbed or smooth wire stretched across the surface), "support bars" (wooden or metal bars spanning the surface of the water that connected 2 sides of the tank), or "other" (any other modification that could reduce access to the water surface such as wooden boards or tires). We also noted presence of escape structures, presence of animal carcasses, and distance from top of trough to the water surface (water level). Escape structures were any object placed in the water that could allow wildlife to escape, including floating boards or logs, as well as intentionally constructed ramps of metal, wire or rocks. We did not search the sediments on the bottom of troughs for animal remains but noted any animal carcasses floating in the water or on the surface of the sediment.

Trough Experiments

We conducted 4 experiments (3 on rectangular and 1 on circular troughs) at the Raymond Wildlife Area to determine how trough modifications affected bat use by simultaneously comparing use at an experimental (modified) trough and a control (unmodified) trough. The 2 rectangular troughs (spaced 100 m apart) had been present at the site with continuous water supply for >2 years. The water surface area of each trough was 7.5 m^2 compared to the mean of 4.3 m^2 (SE = 0.4, $n = 38$) for rectangular troughs in the survey. We placed the 2 circular troughs (also spaced 100 m apart) at the site for this study. They each had a surface area of 4.7 m^2 compared to the mean of 10.5 m^2 (SE = 2.1, $n = 52$) for circular troughs in the survey.

We selected the most common types of modifications, as determined by our survey, to use in our experiments. To reduce confounding effects of trough location, midway through each experiment, we switched the modification to the alternate trough in a crossover design (Dean and Voss 1999). Thus, each trough acted as both the control and the experimental unit in each experiment. Throughout all experiments, we maintained the water level in each trough at 13 cm below the rim, corresponding to the mean water level in the trough inventory.

We simultaneously filmed bat activity at both troughs for 8 hours per night using a black-and-white surveillance camera (1/3" Envirocam, Costar Video, Burbank, California) mounted 2 m high on a pole 4 m from each trough (Fig. 1). We used infrared illumination (HTI-790, 850 nm, Technology Express, Glendale, Arizona) for each camera. A 12-V videocassette recorder (JPI-12VCR, JP Industries, San Jose, California) and video splitter (JPI-BQ4, JP Industries) located 76 m from each camera in a protected location simultaneously recorded the 2 camera images on 1 videotape. At House Rock, we conducted a single-night (80-min) experiment filming simultaneously on 2 rectangular troughs (spaced 100 m apart); at the BLM site, we conducted a single (80-min) experiment on 1 circular trough (described below). All troughs had been present on site with continuous water supply for >1 year.

For each experiment, we asked 2 questions: 1) was the number of approaches at modified and unmodified troughs the same (e.g., did bats avoid modified troughs?), and 2) was the flight behavior at modified and unmodified troughs the same? We defined an approach as any time a bat entered the camera field of view and then left. The number of individuals could not be determined because we were unable to distinguish whether approaches represented separate bats or returns by the same individual. We categorized flight approaches as either "above" (when bats were too high above the surface to obtain a drink), or "surface" (when bats were close enough to the water surface to potentially drink). In addition, when a bat approached a modification we recorded whether it avoided (altered flight path to avoid the modification), passed through (flew between the wires of the modification), made contact (touched the modification and either flew away or fell into the water), or did not interact with the modification (flight was parallel to the modification or no alteration in flight path detected).

Experiment 1A. Bat access to the water surface.—At the Raymond site, we replicated the typical fence found in the trough inventory by placing a 3-strand barbed-wire fence across the center of a rectangular trough. The first strand was 12 cm above the trough rim, the second strand 30 cm above the first, and the top strand 30 cm above the second. We left the other trough unmodified as the control. We filmed both troughs for 5 nights and then switched the fence to the control trough and filmed for 5 more nights from 20–29 May. At the House Rock location, we conducted a single-night experiment on 3 August 2004 to test the results of experiment 1A at a different location. The rectangular troughs were similar to those at the Raymond site. We placed a 3-wire fence across both troughs, filmed simultaneously for 20 minutes, then removed the fence for 20 minutes and repeated this sequence once.

Experiment 1B. Do fences across circular troughs alter bat access to the water surface?—At the Raymond site, we covered the rectangular troughs and placed 2 2.4-m-diameter circular troughs 100 m apart in the same area. We placed 3 strands of barbed wire across one trough as in Experiment 1A. After 3 nights we switched the fence to the control trough and filmed for 2 more nights from 4–8 July. The following night (9 Jul) marked the beginning of the summer monsoons in this area, after which water was widely available. Bat use of troughs dropped and we discontinued experiments at this site. At the BLM site, we conducted a single-night experiment on 26 August to test the results of experiment 1B at a different location. We placed fencing over the water of one 2.4-m diameter circular trough for 20 minutes, then removed it for 20 minutes, and repeated the sequence once.

Experiment 2. How does decreasing the water surface area affect bat access at fenced rectangular troughs?—In this experiment, we placed the same 3-strand fence across both rectangular troughs at Raymond and then reduced the water surface area of one trough by placing plywood boards over half of the water at each end of the trough, effectively reducing the trough length by 50%. After filming bat approaches for 5 nights, we switched the plywood to the control trough and filmed for another 5 nights, from 15–24 June.

Experiment 3. Do support braces across narrow troughs affect bat access?—At the Raymond site, we simulated a long, narrow trough by covering one-half of each rectangular trough used in previous experiments with a tarp until they had the same average dimensions (0.76 m × 4.45 m) as found in the trough survey. We then placed 3 boards (2 cm × 4 cm × 75 cm) at 110-cm intervals across one trough to simulate support braces and left the other trough open as a control. We filmed for 4 nights and then switched the boards, filming for 4 more nights from 26 June–3 July.

Mist-netting for video comparison.—After completing trough experiments, we simultaneously mist-netted and video-taped bats over circular and rectangular troughs at each site to relate video images of bat approaches to the experimental troughs to the species captured in mist nets. We captured bats using 38-mm-mesh 2.6-m × 6-m mist nets (Avinet CH2, Avinet, Inc., Dryden, New York) placed across each trough. We opened the nets at sunset and monitored continuously until either sunrise or midnight, depending on bat activity at troughs. We identified captured bats to species, determined reproductive status and then released them. We captured and handled animals under guidelines of the American Society of Mammalogists and with approval of Northern Arizona University Institutional Animal Care and Use Committee (IACUC Protocol 04–006) and Arizona State Game and Fish research permit number SP747870.

Statistical analyses.—To determine whether modifications caused bats to shift their use to unmodified control troughs, for each experiment we tested whether the total number of approaches at modified and unmodified troughs differed using chi-square analysis (Sokol and Rohlf 1995). We tested whether modifications altered the ability of bats to access the water surface in 2 ways. First, we compared the number of surface and above approaches at modified and unmodified troughs using chi-square contingency table analysis for each experiment separately. We then analyzed video sequences in more detail by categorizing bat behavior as "single approaches" when one approach was separated from another by >1 minute, or as "multiple approaches" when successive approaches by a bat were separated by <1 minute across all experiments. We then compared: 1) the number of single approaches at modified and unmodified troughs that successfully reached the surface, 2) the number of multiple approaches that eventually resulted in reaching the surface at modified versus unmodified troughs, and 3) the number of approaches in a multiple-approach sequence required before reaching the surface at modified and unmodified troughs.

Results

Trough Inventory

For the 90 troughs we measured, 58% were circular, 42% were rectangular, and the most common modifications were fences across both rectangular (18.4%) and circular (30.8%) troughs and braces across rectangular troughs (26.3%). Circular troughs had nearly 3 times the mean water surface area (12.04 m^2, SE = 2.09, n = 52) compared to rectangular troughs (4.26 m^2, SE = 0.44, n = 38). Twelve percent of surveyed troughs were located in pinyon–juniper woodland; 88% were in grasslands or desert scrub similar to the experimental sites. Only 8% of rectangular and 6% of circular troughs included a structure for wildlife to escape from the water. Although we found no bat carcasses floating in any of the troughs, we did not search the sediments for remains. Bats killed and floating in a trough likely would sink to the bottom if not scavenged.

Mist-Netting

We captured 31 bats representing 6 species: long-legged myotis (*Myotis volans*; 1 juvenile female), fringed myotis (*M. thysanodes*; 1 adult male, 1 adult female), western small-footed bat (*M. ciliolabrum*; 1 adult male, 1 adult female), California myotis (*M.*

Table 1. Total number of approaches and percentage of approaches that were at or near the water surface by bats at modified (Mod) and unmodified (Unmod) water troughs in experiments conducted in northern Arizona, USA, 20 May–26 Aug 2004.

Exp./trough type	Site[a]	Modification	Total no. of approaches				% Surface approaches			
			Mod	Unmod	χ^2 (df = 1)	P	Mod	Unmod	χ^2 (df = 1)	P
1A-Rectangular	Ray	Fence	682	468	39.8	<0.001	41	84	208.4	<0.001
1A-Rectangular	HR	Fence	141	230	21.4	<0.001	34	66	35.1	<0.001
1B-Circular	Ray	Fence	26	96	40.2	<0.001	23	73	21.6	<0.001
1B-Circular	BLM	Fence	544	329	53.0	<0.001	20	50	84.4	<0.001
2-Rectangular	Ray	Fence/area	516	305	54.2	<0.001	34	86	145.6	<0.001
3-Rectangular	Ray	Braces	140	95	8.6	<0.001	16	69	69.8	<0.001

[a] Ray = Raymond Wildlife Area; HR = House Rock Wildlife Area; BLM = Bureau of Land Management locations.

californicus; 2 adult females), western pipistrelle (*Pipistrellus hesperus*; 4 adult males, 6 adult females, 2 juvenile females) and pallid bat (2 adult males, 9 adult females, 1 juvenile female). Two *Myotis* spp. escaped from the net before identification. One male was scrotal and 11 females appeared to be postlactation; no others were in obvious reproductive condition, most likely because netting occurred late in the summer. When independent observers viewed the videotapes, captured bats classified as small were western pipistrelle and *Myotis* spp., and those classified as large were pallid bats.

Trough Experiments

For all experiments combined, we recorded 2,049 total approaches at modified troughs by bats, classifying 12% as noninteraction. Of the 1,825 interactions, 95% avoided the modification by altering their flight path. Bats used 90° (53%) or 180° turns (27%) to avoid the fence or bars, adjusted their flight path by flying vertically out of the camera view (8%), or avoided the modification by curving their flight over the wires (12%). In 3.6% (65) of approaches at modified troughs, bats passed through the modification, and in 1.3% (23), they made contact with the modification. Sixteen of the 23 contacts were with wires at troughs with reduced water surface area (exp. 2), a rate of 3.2% of approaches, and 14 of these were large bats. No bats fell into the water and all flew out of the viewing frame after contact but, otherwise, it was impossible to assess whether bats were injured because of contact.

When either rectangular or circular troughs were modified by placing 3 strands of barbed wire across the surface, the percentage of approaches at or near the water surface was roughly one-half or less of that at unmodified troughs (Table 1) in all experiments. In contrast, although the number of approaches recorded at fenced troughs was 37% higher than unmodified troughs, in 2 of the 6 experiments we recorded more approaches at modified troughs; while in the other 4 experiments, we recorded more approaches at the modified trough (Table 1). In all of the experiments, we found no difference in the response of bats classified as large versus those classified as small ($P = 0.14$, 0.47, and 0.26 for Raymond exp. 1A, 1B, and 2, respectively).

When we simulated braces across a narrow rectangular trough, we found the total number of approaches was higher at modified troughs, while the percentage of approaches at or near the water surface was roughly 25% of that at unmodified troughs (Table 1). Again, we detected no difference in responses of large versus small bats in their response to modification ($P = 0.23$).

When approaches across all experiments at Raymond Wildlife Area were categorized as either "single approaches" (approaches separated in time by >1 min) or "multiple approaches" (approaches separated in time by <1 min), we found that the percentage of single approaches at or near the water surface was ~3 times higher at unmodified troughs compared to modified troughs (71% vs. 25%; $\chi^2_1 = 20.2$, $P \leq 0.001$). Likewise, in sequences in which bats approached troughs multiple times in rapid succession ("multiple approaches"), they never reached the surface in 39% of the cases at modified troughs compared to 3% at unmodified troughs ($\chi^2_1 = 44.1$, $P \leq 0.001$). In these multiple-approach sequences, the mean number of approaches required before a successful approach at the water surface was 1.8 (SE = 0.29) at modified troughs compared to 0.3 (SE = 0.07) at unmodified troughs ($Z_1 = 5.25$, $P < 0.001$).

Discussion

Our results suggest that trough modifications altered the behavior of bats approaching modified troughs in all experiments. The most common effect was the decreased percentage of approaches at the water surface, suggesting that bats approaching modified troughs expended more effort and flight time to obtain a drink. This was supported in our analyses that divided approaches into those occurring in rapid succession (multiple-approach sequences) and those that were separated from other approaches by >1 minute (single approaches). Bats made 3 times more single approaches and 6 times more approaches in multiple-approach sequences over modified troughs before they successfully reached the water surface. In addition, bats were 10 times more likely to make multiple approaches without accessing the water surface at modified troughs than at unmodified troughs. Although the duration of the experiment at the 2 additional sites (House Rock and BLM) was shorter, the results were similar, with a 2-fold higher success rate at reaching the surface at unmodified troughs versus modified troughs. In addition to an increased number of approaches to access the water surface, in all experiments, flight paths were often altered at modified troughs, requiring sharp turns rather than a smooth, arcing swoop over the water.

The timing of these experiments corresponded to the most energetically demanding time for most southwestern bat species because of pregnancy and lactation (O'Farrell et al. 1971, Kurta et al. 1990). The mean daily energy requirement of lactation is twice that of pregnancy and 3 times that of nonreproductive periods (Kurta et al. 1990). To avoid negatively affecting bats during our experiments, we did not mist-net until late in the season. As a result, most of the bats we handled were not in reproductive condition. However, given that adult females commonly were captured in our mist-netting sessions, it is likely that they were using these troughs earlier in the season (Rabe 1999, C. L. Chambers, Northern Arizona University, unpublished data). As a result, the flight modifications and the need to make multiple approaches to drink successfully at modified troughs could increase energetic demands during a critical period of the reproductive cycle.

One potential criticism of our experimental design was that it lacked the washout period often included in crossover designs to account for any residual effects of the experimental manipulation after it had been switched or removed (Dean and Voss 1999). If residual effects occurred, we should have detected a shift in behavior from the first night after moving the modification compared to later nights at Raymond Ranch, a shift that was not evident in visual inspection of our data. Likewise, if strong residual effects were present, they should have reduced our power to detect differences between modified and unmodified troughs in the very short-duration experiments at House Rock and BLM, in which modifications were shifted every 20 minutes. Residual effects in this case should have made it impossible to detect differences among treatments, when in fact we found significant effects. These results indicated that bats responded almost immediately to the presence or absence of modifications. In addition, the greater abundance of bats at our House Rock and BLM sites yielded total numbers of approaches in a single night that approximated those across several nights at Raymond Ranch; thus, sample sizes for tests in both experiments were similar, in spite of differences in experiment duration.

One aspect that we did not address was whether bats adapt their behavior to modifications over time, and the negative responses we documented, therefore, would decrease as bats became familiar with the presence of modifications. However, at least over the relatively short term of our experiments, bats did not increase surface approaches over time at modified troughs, as would be expected if adaptation over time were occurring. Even if resident bats could potentially adapt to trough modifications through time, modifications for migratory bats would be novel encounters at each stopover site.

Overall, we found no evidence that large and small bats responded differently to modifications. However, size alone may not be a good predictor of flight performance because of the variability in aspect ratio and wing-loading across species. A major limitation of our video method was that the resolution was not great enough to allow for species identification, although we could distinguish large from small bats. Simultaneously recording bats while mist-netting allowed us to assign some species to each size category, but we did not capture all species documented to occur in the area in previous studies (Hoffmeister 1986, Rabe 1999, C. L. Chambers, unpublished data).

The large bats we observed in our experiments likely were pallid bats, a maneuverable bat with low wing-loading despite weighing 3–4 times that of small bats (Harvey et al. 1999). Although we did not capture the intermediate-sized Mexican free-tailed bat (*Tadarida brasiliensis* [11–15 g]) or big brown bat (14–21 g), both have higher wing-loading than pallid bats (Harvey et al. 1999) and may be more negatively affected by trough modifications. Determining species-specific responses to modifications remains an important challenge for future studies.

Only 1.3% of 1,825 bat approaches resulted in contact with a modification and, in all cases, no bats struck the modification in such a way to knock them into the water. However, most of these occurred at smaller-surface-area troughs, where collisions averaged 1.6 per night. We believe these observations indicate increased potential for mortality or injury, with the risk being higher at smaller troughs. In this respect, modification of rectangular troughs may be more likely to result in negative effects on bats for 2 reasons. First, the mean water surface area of rectangular troughs in our survey was much smaller than that of circular troughs. Second, when a single fence or support brace is placed across a circular trough, the length of the longest potential flight path is not reduced if bats fly parallel to the modification. This is not true for modifications across rectangular troughs.

During our mist-netting, we observed 3 bats that fell from nets into the water. In 2 cases bats swam to the edge of the trough and escaped either by using a rock ramp or by climbing up the rough inner wall of the trough. Given that many troughs in our survey were smooth-walled steel and did not contain an escape structure, we believe bats falling into these troughs may less easily escape. Although one bat in our experiments was able to launch into flight from the water surface, injury, hypothermia or exhaustion may prevent a bat from achieving flight in the absence of a means to exit the water.

One rancher reported finding several dead bats in a 2-m-diameter circular trough with no modifications but with a water level maintained >20 cm below the rim (D. Carroll, private rancher, personal communication). In this case, bats may have collided with the vertical wall above the water while attempting to drink or forage at the surface. Of the troughs in our survey, 38% had water levels $\geq$10 cm below the rim (and as much as 26 cm). Allowing water levels to fall well below the rim also effectively reduces the water surface area available to bats due to the angle of approach necessary to avoid the trough wall and still access the water surface. Given the strong effect of reducing surface area on the number of collisions we documented in this study, we believe low water levels combined with trough modifications could increase the potential for bat mortality.

The majority of bats did not make contact with or fly between fence wires or under bars. Instead, changes in their flight path allowed bats to avoid the modification using primarily 90° and 180° turns. Experimental modifications were limited to 3 strands of standard-diameter barbed wire and wooden bars across the water surface. Modifications with greater complexity or smaller-diameter wire potentially could act as a greater threat. Indeed, if wires were thin enough and spaced more closely together, fence modifications could resemble the harp traps commonly used to capture bats.

Management Implications

Our data demonstrate that trough modifications may reduce the ability of bats to access the water surface and, thereby, potentially increase the energetic costs of drinking. We documented no mortality due to modifications during our study, and overall rate of collision with modifications was very low, suggesting that trough modifications we studied may not need to be mitigated. However, we argue caution be exercised in future modifications for several reasons.

First, although all bats that collided with modifications were able to fly away, we were unable to assess whether contact resulted in injury. Second, even though the overall rate of collision was low, most of these occurred at troughs with smaller surface area, where collisions averaged 1.6 per night. Third, most of these collisions were large-bodied bats, suggesting that the effects of modifications may differentially affect some species over others. Fourth, our inability to determine bat species on our videotapes leaves open the possibility that some large-bodied, less-maneuverable species are excluded from modified tanks. As a result, we recommend that modifications be removed or altered, especially for small troughs, so they do not span the entire water surface. In many cases this can be achieved relatively easily and inexpensively (e.g., for narrow troughs that need additional support for the sidewalls, trough supports can be placed on the outside of the trough rather than across the water surface). For troughs that retain modifications, adding an escape structure of rock, wood, or metal on the inside edge would allow bats to crawl out of the water and would be relatively easy and inexpensive. For smaller troughs with reduced surface area, a separate trough could be installed for each pasture. A second trough will cost less than $1,000 depending on size and type selected, may be cost-shared through government conservation programs on private land, and would have the added benefit of reducing soil compaction and erosion. Finally, adjusting float valves to maintain the water level at or near the trough rim provides maximum water surface area and minimizes the risk of collisions with the trough wall.

Acknowledgments

This study was funded by a grant from the Wildlife Habitat Management Institute of the Natural Resources Conservation Service and a student scholarship from Bat Conservation International. We sincerely thank D. Belitsky, manager of the Raymond Wildlife Area, and M. Brown, manager of the House Rock Wildlife Area for support, and the Arizona Game and Fish Department for permission to film troughs on the wildlife areas. J. Gagnon provided video design and equipment suggestions. We thank D. Kuhns for help in the field, C. Calvo, D. Pokrajac, M. Evans, C. Boone, and S. Penrod for assistance with the laborious task of viewing and analyzing videotapes. We thank 2 anonymous reviewers for their comments that greatly improved the manuscript.

Literature Cited

Andrew, N. G., V. Bleich, A. Morrison, L. Lesicka, and P. Cooley. 2001. Wildlife mortalities associated with artificial water sources. Wildlife Society Bulletin 29:275–280.

Brown, D. E. 1994. Biotic communities: southwestern United States and northwestern Mexico. University of Utah, Salt Lake City, USA.

Carpenter, R. E. 1969. Structure and function of the kidney and water balance of desert bats. Physiological Zoology 42:288–302.

Dean, A., and D. Voss. 1999. Design and analysis of experiments. Springer-Verlag, New York, New York, USA.

Entwhistle, A. C., P. A. Racey, and J. R. Speakman. 1997. Roost selection by the brown long-eared bat *Plecotus auritus*. Journal of Applied Ecology 34: 399–408.

Evelyn, M. J., D. A. Stiles, and R. A. Young. 2004. Conservation of bats in suburban landscapes: roost selection by *Myotis yumanensis* in a residential area in California. Biological Conservation 115:463–473.

Harvey, M. J., J. S. Altenbach, and T. L. Best. 1999. Bats of the United States. Arkansas Game and Fish Commission, Little Rock, USA.

Hoffmeister, D. F. 1986. The mammals of Arizona. University of Arizona, Tucson, USA.

Kolb, A. 1984. Schwimmen, starten vom wasser und orientierung einheimischer fledermaeuse. Zeitschrift Fur Saugetierkunde 49:1–6. [In German.]

Kurta, A., T. H. Kunz, and K. A. Nagy. 1990. Energetics and water flux of free-ranging big brown bats (*Eptesicus fuscus*) during pregnancy and lactation. Journal of Mammalogy 71:59–65.

O'Farrell, M. J., E. H. Studier, and W. G. Ewing. 1971. Energy utilization and water requirements of captive *Myotis thysanodes* and *Myotis lucifugus* (Chiroptera). Comparative Biochemical Physiology 39:549–552.

Rabe, M. J. 1999. Bat habitat use in pinyon–juniper woodland and grassland habitats in northern Arizona. Thesis, Northern Arizona University, Flagstaff, USA.

Rabe, M. J., T. E. Morrell, H. Green, J. O. deVos, and R. Miller. 1998. Characteristics of ponderosa pine snag roosts used by reproductive bats in northern Arizona. Journal of Wildlife Management 62:612–622.

Sokol, R. R., and F. J. Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. Third edition. W. H. Freeman, New York, New York, USA.

Waldien, D., and J. P. Hayes. 2001. Activity areas of female long-eared *Myotis* in coniferous forests in western Oregon. Northwest Science 75:307–314.

Waldien, D., J. Hayes, and E. Arnett. 2000. Day-roosts of female long-eared *Myotis* in Western Oregon. Journal of Wildlife Management 64:785–796.

Webb, P. I., J. R. Speakman, and P. A. Racey. 1995. Evaporative water loss in two sympatric species of vespertilionid bat, *Plecotus auritus* and *Myotis daubentoni*: relation to foraging mode and implications for roost site selection. Journal of Zoology, London 235:269–278.

Stuart R. (Stu) Tuttle (photo) is a Wildlife Biologist with the Natural Resources Conservation Service in Flagstaff, Arizona. He recently completed his Master's degree at Northern Arizona University. He received his B.S. in Vocational Agriculture form Colorado State University. He served as Secretary and is now President-elect for the Arizona Chapter of The Wildlife Society and Program Committee Chair for the 2007 Wildlife Society Conference in Tucson. His professional interests are in habitat restoration and wildlife–livestock interaction. At home, he and his wife, Mary, enjoy competing in dog agility. ***Carol L. Chambers*** is an Associate Professor of Wildlife Ecology with the School of Forestry at Northern Arizona University. She worked as a Faculty Research Assistant at Oregon State University while completing her Ph.D. in Wildlife Sciences. She received her M.S. in Forestry

and B.S. in Biology from the University of Kentucky. She has been a board member, web site manager, and is currently President for the Arizona Chapter of The Wildlife Society. She has been a member of national and local chapters of TWS since 1992. Her research is focused on wildlife habitat relationships. ***Tad C. Theimer***, an associate professor in the Department of Biological Sciences at Northern Arizona University, received his B.S. in biology from University of the Pacific, his M.S. in zoology from Colorado State University, and his Ph.D. in zoology from Northern Arizona University. A past president of the Arizona Chapter of The Wildlife Society, his research interests are in bird and mammal ecology.

Special Section Associate Editor: Krausman.