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# FACTORS AFFECTING BAT HOUSE OCCUPANCY IN COLORADO

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ABSTRACT—Artificial roosts known as bat houses have been developed to replace natural roosts that are destroyed and to create new roosts where they are lacking. I investigated the effects of variables related to bat house characteristics and ecological conditions on patterns of roost occupancy in 95 bat houses. Bat houses seem to have been used exclusively as day roosts, with an overall occupancy rate of 11.6%. The presence of bats roosting in the immediate area prior to the placement of the house was an important predictor of occupancy. When bats were already present at a site, the occupancy rate increased to 63.6%. Likelihood of occupancy also was increased by providing houses with larger landing areas, by mounting them on buildings instead of trees, and by placing houses in areas with low canopy cover and low levels of human disturbance. Bat houses are probably best used when a roost is going to be destroyed, or a colony excluded, and when the houses can be placed in the immediate area of the old roost.

RESUMEN—Perchas artificiales (dormideros) conocidas como casas para murciélagos han sido desarrolladas para reemplazar perchas naturales que son destruidas y para colocar nuevas perchas en sitios que no las tienen. Investigué los patrones de ocupación de 95 casas para murciélagos con respecto a sus características estructurales así como con respecto a variables ecológicas. Las casas parecieron haber sido utilizadas exclusivamente durante el día, con 11.6% de las casas ocupadas. La presencia de murciélagos en perchas en sectores aledaños antes de colocar las casas fue el mejor pronosticador de la ocupación de éstas. La tasa de ocupación aumentó a 63.6% cuando algunos murciélagos ya se hallaban en la zona. La probabilidad del uso de las casas aumentó cuando las casas tuvieron áreas de aterrizaje más grandes, fueron instaladas en edificios y no en árboles, y fueron puestas en áreas con cubierta de dosel bajo y con bajo impacto antropogénico. Parece mejor usar las casas para murciélagos cuando una percha va a ser destruida, o una colonia va a ser excluida, y cuando las casas pueden ser colocadas en áreas inmediatas a perchas antiguas.

In recent years, the importance of roost sites has come to the forefront of bat protection and management. Artificial roosts known as bat houses have been increasingly used to replace natural bat roosts that are being destroyed and to provide roosts for bats excluded from buildings and caves (Neilson and Fenton, 1994; Williams and Brittingham, 1997; Brittingham and Williams, 2000). Recent research has focused on use of bat houses in particular situations, such as under bridges (Arnett and Hayes, 2000) or at the entrance to displaced maternity roosts (Brittingham and Williams, 2000). However, few studies have been published concerning the effectiveness of these artificial roosts as managers and conservationists typically place them.

It is generally considered that bats select roosts based on temperature (Vaughan, 1987; Campbell et al., 1996; Entwistle et al., 1997), predation risk (Rydell et al., 1996; Vonhof and Barclay, 1996, 1997), and accessibility (Sedgeley and O'Donnell, 1999). Tree height and canopy cover are also important for determining occupancy of tree roosts (Brigham et al., 1997). In addition, roost switching can lead to suites of roost sites being important, not just single roosts (Brigham et al., 1997; Kalcounis and Brigham, 1998). Maternity colonies might prefer different combinations of variables than solitary bats. In particular, warm temperatures are important for reproductive females, but not for males (Kunz, 1982; Hamilton and Barclay, 1994). It is reasonable to assume that bats might select artificial roosts based on similar considerations. If factors governing the use of

TABLE 1—Definition of the disturbance levels used to classify human disturbance for bat houses censused in Colorado from May through September 1997. Disturbance level is based on the estimated level of both foot and vehicular traffic within a 100-$m^2$ circle surrounding each bat house.

| Disturbance | Traffic level per day |
|---|---|
| 1 | 0–5 people, 0 vehicles |
| 2 | 6–10 people, 1–5 bicycles |
| 3 | 11–15 people, 1–10 cars |
| 4 | 16–50 people, 11–25 cars |
| 5 | >50 people, >25 cars |

these roosts can be determined, the effectiveness of artificial roosts as a management tool could be improved by tailoring them towards characteristics that increase the likelihood of their occupancy. Here I address a number of variables of potential importance in roost selection and attempt to elucidate those that might influence occupancy of bat houses.

METHODS—Ninety-five bat houses (Appendix 1) placed by environmental organizations, government agencies, and private citizens in 9 counties in Colorado were identified and monitored from the end of May through the beginning of September 1997. For each bat house I recorded 22 variables: volume; height above ground; number and width of cavities; landing area size; color (ordinal scale, 1 to 5, lightest to darkest); aspect; roughness of the roosting surface (ordinal scale, 1 to 3, smoothest to roughest); physical condition of the bat house (ordinal scale, 1 to 5, new to decrepit); type (building, tree, or pole), and height of the mount. Inside a 100-$m^2$ area surrounding the bat house, I recorded tree density, percent canopy cover, and elevation, and I estimated the level of human disturbance (Table 1) and the percentage of daylight hours during which the bat house was exposed to sunlight. I measured distances to the nearest tree or building, permanent water source, and bat house. I inquired as to how long the bat house had been hanging and whether bats had been seen roosting in the vicinity prior to the mounting of the bat house. Roosting typically was observed when a roost was present in the building on which the bat house was mounted or when bats roosted in the eaves of the building. I observed the interior of the bat house and noted the presence of any non-bat species (wasps and spiders). Finally, I confirmed the presence of bat activity in the area by surveying with a bat detector (Bat Box III; Stag Electronics, Steyning, United Kingdom) for approximately 3 hours beginning at dusk on a single evening.

I checked most bat houses for occupancy at approximately 15-d intervals ($n$ = 80); however, a few ($n$ = 15) were only checked every 30 d. I established occupancy by visual observation from below the bat house with the aid of a flashlight. I visually checked the mount and the ground underneath the entrance of all bat houses for the presence of guano. Guano was present under all occupied bat houses, suggesting that it would be observed at the base of any bat house receiving significant use. I observed approximately half ($n$ = 40) of the bat houses from sunset until 0200 h on a single night to determine whether they were used as night roosts. I checked each bat house every 15 minutes using red lights, and I used a bat detector (Bat Box III) to detect any bat approaching or entering the bat house.

If I observed bats roosting in a bat house, I identified them to genus or species by visual observation in an effort to minimize disturbance that potentially could affect use of the bat houses. *Eptesicus fuscus* could be identified to species, whereas *Myotis* could be identified only to genus. In 1 instance where a bat could not be identified from below, it was mistnetted upon exiting the bat house and identified as *M. lucifugus*.

For continuous variables, I compared the means between used and unused bat houses using Kruskal-Wallis tests, because the assumptions of parametric tests were not met. I used Chi-square tests to compare count variables. To compare aspect (a circular variable) between the groups, I used the Mardia-Watson-Wheeler test (Batschelet, 1981). In addition, I used logistic regression to reveal variables important in discriminating between bat houses that were occupied and those that were not. I used both forward and reverse stepwise logistic regressions to determine the best model, the Hosmer-Lemeshow test to confirm the linearity of the relationships (Hosmer and Lemeshow, 1989), and the likelihood ratios to determine $P$ values. This logistic regression is not intended to specify a specific model to be followed in the placement of bat houses, but to gain a better understanding of what is affecting their use (Bekoff et al., 1987). To avoid excluding potentially important variables, I included several that approached statistical significance ($0.05 \leq P < 0.1$) in the results and discussion.

RESULTS—Of the 95 bat houses, 47 were placed along the Front Range in and around Colorado Springs, Boulder, and Denver, and were located in preserved areas, such as regional parks and county open space. These bat houses were generally placed on trees or on buildings, such as nature centers or mainte-

TABLE 2—Means (and *SD*) of variables associated with bat house use for occupied ($n = 11$) and unoccupied bat houses ($n = 84$) censused in Colorado from May through September 1997. *P* values were obtained using Chi-square tests or Kruskal-Wallace tests. Variables remaining significant following sequential Bonferroni correction are indicated by + ($P < 0.1$) and * ($P < 0.001$).

| Variable | Occupied | Unoccupied | *P* |
|---|---|---|---|
| Volume (cm$^3$) | 51,765 (44,677) | 35,840 (38,594) | 0.256 |
| Height above ground (m) | 4.5 (1.1) | 4.1 (1.2) | 0.277 |
| Number of cavities | 3.1 (0.8) | 3.0 (1.5) | 0.256 |
| Width of cavities (cm) | 2.3 (1.0) | 3.1 (2.2) | 0.175 |
| Landing area size (cm) | 12.1 (7.1) | 7.4 (5.5) | 0.047 |
| Color (ordinal) | 2.3 (1.0) | 2.6 (1.3) | 0.865 |
| Aspect (degrees) | 155.8 | 278.4 | 0.201 |
| Roughness (ordinal) | 2.4 (0.5) | 2.2 (0.6) | 0.415 |
| Physical Condition (ordinal) | 1.0 (0.0) | 1.6 (0.8) | 0.013 |
| Mount type | — | — | 0.003+ |
| Mount height (m) | 5.6 (1.6) | 10.5 (6.8) | 0.119 |
| Tree density (per 100 m$^2$) | 1.5 (2.7) | 5.4 (7.0) | 0.005 |
| Canopy cover (%) | 5 (4) | 31 (30) | 0.028 |
| Elevation (m) | 1,826 (337) | 1,905 (348) | 0.677 |
| Disturbance (ordinal) | 2.2 (1.2) | 2.0 (1.2) | 0.646 |
| Exposure to sunlight (% of daylight) | 45 (24) | 39 (32) | 0.325 |
| Distance to tree/building (m) | 17 (25) | 28 (98) | 0.023 |
| Distance to water (m) | 110 (143) | 380 (833) | 0.870 |
| Distance to bat house (m) | 157 (320) | 214 (321) | 0.678 |
| Time since placement (yr) | 3.5 (2.1) | 2.7 (1.2) | 0.265 |
| Prior roosting in area | — | — | <0.001* |
| Presence of non-bat species | — | — | 0.033 |

nance sheds. A few bat houses in this region were located on residences on the outskirts of the cities. In the Saguache National Forest, 8 bat houses were mounted on trees in remote campgrounds. Thirty-nine bat houses were placed in the Durango area. This area was primarily rural farmland, and the bat houses were mounted on farm residences or other buildings and on trees in campgrounds surrounding McPhee Reservoir. The final bat house was placed on the side of a home in Las Animas and was surrounded by dry pasture and irrigated farmland. Overall, 40 bat houses were mounted on trees, 42 on buildings, and 13 on poles.

Bats used 11 bat houses during the study, for an overall occupancy rate of 11.6%. When only bat houses where bats had been roosting in the area before placement were considered ($n = 11$), the occupancy rate increased to 63.6%. Of the occupied bat houses, 6 were inhabited by *E. fuscus,* 2 by *Myotis,* 1 by *M. lucifugus,* and 2 had fresh guano at the base of the bat house on 2 separate occasions. One of the *E. fuscus* houses contained a small colony (about 20 bats). All other bat houses were occupied by 1 or 2 individuals. All observed occupancy of bat houses involved day-roosting bats. Sampling with bat detectors indicated that bats foraged within 15 m of every bat house and, therefore, had the opportunity to recognize the roosts. Bat activity was qualitatively lower in the forested sites, but in several cases where bat houses were mounted on trees in narrow strips of woodland, foraging activity was high in adjacent fields.

Univariate analysis (Table 2) yielded 7 factors showing statistical significance; however, only 1 variable, bats roosting in the area prior to bat house placement, remained significant following a sequential Bonferroni correction for the large number of variables (Rice, 1989). One additional variable, mount type, had a *P* value < 0.1, indicating that perhaps bat houses mounted on buildings were more likely to be inhabited than those mounted on trees. In fact, no bat houses mounted on trees were occupied at any point during the study.

TABLE 3—Forward stepwise logistic regression parameter estimates discriminating between occupied and unoccupied bat houses ($n$ = 95) censused in Colorado from May through September 1997. Levels of statistical significance indicated by + ($P < 0.1$), * ($P < 0.05$), and ** ($P < 0.001$).

| Variable | β | *SE* | Odds ratio | −2 Log LR |
|---|---|---|---|---|
| Canopy cover | −1.36 | 0.90 | 0.26 | 2.87+ |
| Disturbance | — | — | — | 7.99* |
| Disturbance 2 | −2.77 | 1.61 | 0.06 | — |
| Disturbance 3 | −3.61 | 1.84 | 0.03 | — |
| Disturbance 4 | −4.04 | 2.06 | 0.02 | — |
| Landing area size | 0.96 | 0.61 | 2.60 | 3.04+ |
| Known prior roosting | 6.68 | 1.11 | 794.02 | 28.56** |

I included 16 variables in a forward stepwise logistic regression, and 4 of these were entered into the final model. Mount type could not be included in the analysis because it contained a 0 value in the tree-mounted category, and aspect could not be included because of its circular nature. The rest of the excluded variables (mount height, exposure to sunlight, elevation, and roughness) were removed because it was necessary to reduce the number of correlated variables for the analysis (Hosmer and Lemeshow, 1989). Elevation, mount height, exposure to sunlight, and canopy cover were correlated with one another. I chose to include canopy cover because it had the strongest univariate relationship with roost occupancy and performed best in the multivariate analysis. The logistic regression correctly classified 95.8% of the total bat houses as either used or unused, but only classified 63.6% of the used bat houses correctly. It yielded 2 log-likelihood ratios that were significant at $P < 0.05$ and 2 with $P < 0.1$ (Table 3). Lower levels of canopy cover ($P < 0.1$), lower levels of human disturbance ($P < 0.05$), larger landing areas ($P < 0.1$), and roosting in the area prior to the mounting of the bat house ($P < 0.001$), seemed to be important in determining if a bat house was occupied. When the logistic regression was run without the prior roosting variable, it failed to distinguish between inhabited and uninhabited bat houses (correct classification of inhabited bat houses = 19.2%).

DISCUSSION—Inhabited bat houses tended to be mounted on buildings with relatively low disturbance, low percent canopy cover, and larger landing areas. Both *E. fuscus* (Kalcounis and Brigham, 1998; Rabe et al., 1998) and *M. lucifugus* (Barclay and Cash, 1985) roost in trees, so the lack of occupancy of tree mounted bat houses is not because the species occupying the bat houses do not roost in forested areas. However, tree sites also had greater average canopy cover (54%), and reduced roosting in high canopy cover areas has been reported in forest-dwelling bats (Campbell et al., 1996; Vonhof and Barclay, 1996; Callahan et al., 1997; Vonhof and Barclay, 1997). It also could be that tree roosts in forested areas are an abundant resource, making it less likely that artificial roosts will be occupied. However, a recent study with artificial roosts constructed to closely mimic natural tree roosts found that 17 of 20 roosts were occupied over 2 summers (Chambers et al., 2002). This suggests that bats were not using bat houses in wooded areas because the bat houses were not similar enough to naturally occurring roosts. In forested areas, artificial roosts such as those designed by Chambers et al. (2002) might be more successful.

Disturbance was not important to occupancy when analyzed on its own, probably because all of the unoccupied tree sites were in low disturbance areas. However, its significance in the logistic regression indicated that it played a role when other factors were appropriate for occupancy. If a bat house is generally suitable, then high disturbance in the area might prevent it from being utilized. Larger landing areas might allow for easier access to the bat house.

None of the remaining variables related to roost temperature (color, aspect, exposure to sunlight) significantly affected occupancy. This might be because most bat houses were occupied by solitary males, for whom warm temperatures might be of less importance because males frequently employ torpor during the day-roosting period (Kunz, 1982; Hamilton and Barclay, 1994). In addition, I considered occupancy over the entire summer, and bats can switch between roosts with different thermal regimes as ambient temperature and reproductive status change (Brittingham and Williams, 2000; Kerth et al., 2000). Switching would make it difficult to detect the effects of roost temperature based on my analyses.

Occupied bat houses tended to have had bats roosting in the area prior to the placement of the bat house. The failure of logistic regression to accurately classify roosts with this variable removed indicated that other factors might become important only when bats already are roosting in the area. It has been shown that high occupancy rates (>50%) can occur when bat houses are placed on the same side of the building as the entrance to excluded maternity colonies (Brittingham and Williams, 2000). However, in a similar exclusion study where bat houses were placed in the same general region as the excluded roosts, maternity colonies failed to relocate into bat houses (Neilson and Fenton, 1994).

The length of time a bat house had been hanging had no significant effect on occupancy. This might be related to the tendency for occupied bat houses to be located near roosts, so that the length of time required to discover the new roost would be relatively short.

Bat houses have been proposed as a way to replace roosts that are being destroyed. The fact that 64% of the bat houses with bats roosting in the area prior to placement were occupied is encouraging from this conservation perspective. If a roost is at risk or must be destroyed, placing bat houses near the entrance to the old roost might provide replacement roosts for the bats involved. By placing these replacement roosts on buildings with low canopy cover and low disturbance, and providing them with large landing areas, it might be possible to increase occupancy. However, this study indicated that the use of these artificial roosts to introduce or reintroduce species to currently uninhabited areas does not hold much promise. In particular, there was no indication that placing bat houses on trees that were not known roosts increased the roosting of bat species in an area; however, other types of artificial roosts might be more successful in this regard. This study also provided evidence that species commonly encountered in buildings were more likely to use bat houses. Thus, successful relocation of other species to these artificial roosts is likely to be low. Finally, bat houses were rarely used by maternity colonies, which are of greater importance from a conservation perspective than solitary roosts.

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Appendix 1—Number of bat houses occupied out of total number of bat houses in each county. Adams County, 2 of 4; Boulder County, 0 of 21; Denver County, 0 of 2; El Paso County, 1 of 14; La Plata County, 6 of 41; Las Animas County, 1 of 1; Larimer County, 1 of 3; Montezuma County, 0 of 1; Saguache County, 0 of 8.