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Bat use of a high-plains urban wildlife refuge

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Abstract Bats are significant components of mammalian diversity and in many areas are of management concern. However, little attention has been given to bats in urban or prairie landscapes. In 1997 and 1998, we determined species richness, relative abundance, roosting habits, and echolocation activity of bats at Rocky Mountain Arsenal National Wildlife Refuge (RMA), the largest urban unit in the United States refuge system, located on the high plains near Denver, Colorado. An inventory using mist nets revealed 3 species foraging at this site: big brown bats (*Eptesicus fuscus*), hoary bats (*Lasiurus cinereus*), and silver-haired bats (*Lasionycteris noctivagans*). Big brown bats comprised 86% of captures ($n=176$). This pattern was consistent with continental-scale predictions of bat species richness and evenness based on availability of potential roosts. Relative abundance based on captures was similar to that revealed by echolocation detector surveys, except that the latter revealed the likely presence of at least 2 additional species (*Myotis* spp. and red bats [*Lasiurus borealis*]). Echolocation activity was significantly greater ($P=0.009$) in areas with tree or water habitat edges than in open prairie, suggesting that maintaining such features is important for bats. Big brown bats commuted greater distances (9.2–18.8 km) from roosts in urban core areas to foraging sites on the refuge than typically reported for this species elsewhere, emphasizing the value of the site to these bats. Urban refuges can provide habitat of importance to bat populations, but may be characterized by abundant bats that roost in buildings if a variety of other kinds of roosting habitats are unavailable.

Key words activity, bats, big brown bat, *Eptesicus fuscus,* habitat use, hoary bat, *Lasionycteris noctivagans, Lasiurus cinereus,* prairie, roosts, silver-haired bat, urban wildlife

Given the continued growth and sprawl of cities, urban wildlife refuges and parklands may become increasingly important to conserve local biological diversity. Bats are significant components of mammalian biodiversity in many areas (Nowak 1994), are of economic importance as consumers of insect pests (Whitaker 1995), and there is concern over the population status of some species (United States Fish and Wildlife Service 1994). There continue to be major gaps in knowledge of patterns of abundance, distribution, roosting requirements, and foraging habitat of bats of North America (Pierson 1998). Although researchers have investigated the importance of land management for bats, most studies have focused specifically on echolocation activity indices and roost-site selection in forested landscapes (e.g., Thomas 1988, Humes et al. 1999, Jung et al. 1999). Numerous studies have assessed bat foraging activity in various habitat types in and around villages and cities in Europe (Racey 1998). However, information about bat use of urban parklands and refuges in the United States (U.S.) is very limited (Kurta and Teramino 1992). Similarly, little detailed information is available on composition of bat communities of high-plains habitats in North America (Sparks and Choate 2000).

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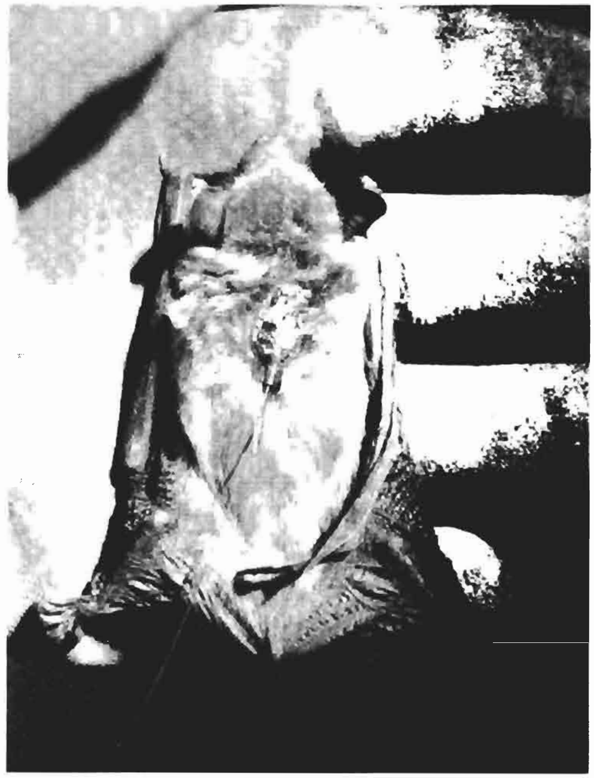
The primary objectives of our study were to determine species richness, relative abundance, roosting habits, and activity patterns, in relation to habitat features, for bats at an urban, prairie wildlife refuge. Our secondary objectives were to compare these findings with general predictions about species richness and relative abundance of bats generated by past continental-scale biogeographic analyses (Humphrey 1975) and to compare inventory methods based on captures in mist nets with computer recordings of echolocation calls. Recent research in other habitats suggests that a combination of both approaches may yield the most thorough results (Kuenzi and Morrison 1998, O'Farrell and Gannon 1999).

Methods

Study area

We conducted our study at Rocky Mountain Arsenal National Wildlife Refuge (RMA), 16 km northeast of Denver, at Commerce City, Adams County, Colorado, elevation 1,600 m (Cohn 1999). RMA was a 6,900-ha high-plains wildlife refuge bordered to the south and west by industrial and residential development (Figure 1) and to the north and east by agricultural areas and the Denver International Airport. The population of the urban area was about 2 million people. Topography was flat to gently rolling, and there were no caves, mines, cliffs, or rocky outcrops that could harbor bat roosts. Vegetation was primarily remnant short-grass prairie or non-native grassland, with small, sparsely scattered cottonwood (*Populus sargentii*) groves; land cover was grasslands and prairie dog (*Cynomys ludovicianus*) communities (86%), woodlands (7%), and wetlands (5%, Hoff 1998). Rocky Mountain Arsenal was undergoing remediation from past use as a chemical production site, primarily in a core area near the center of the refuge (Allen and Otis 1998). The RMA was the largest urban wildlife refuge in the U.S. system (Cohn 1999).

Figure 1. The interface of the urban and high-plains environments at Rocky Mountain Arsenal National Wildlife Refuge. Photo courtesy of Ecotoxicology Laboratory, Department of Fishery and Wildlife Biology, Colorado State University.



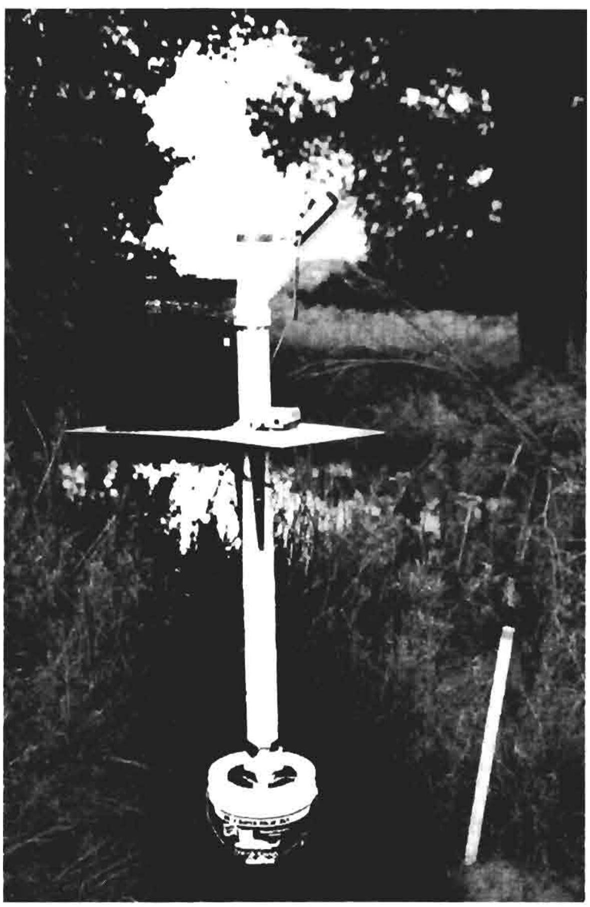
Big brown bat in hand with transmitter attached.

Capture and telemetry

We captured bats in mist nets for radiotagging and to determine species richness, relative abundance, and reproductive status. We set mist nets along drainage canals, across small ponds and edges of lakes, and perpendicular to patches of trees and shrubs. Mist nets (6–18 m in length, 2.1 m high) were set at or near ground or water level. We set mist nets on 53 nights (371 6-m net nights) at 18 sites on RMA: 26 nights from 30 May to 20 August 1997, and 27 nights from 26 May to 13 August 1998. On 3 of the 53 nights, we extended and stacked nets to about 10 m above ground. We generally deployed nets from sunset until midnight and tended them continuously. We identified captured bats to species and noted sex and reproductive condition based on external morphological characters

(Racey 1988, Fitzgerald et al. 1994). We assigned bats to adult or juvenile age categories based on degree of closure of the phalangeal epiphyses (Burnett and Kunz 1982). We generally released bats within 1 hour of capture. We compared sex ratios within species for deviation from an expected 1:1 proportion using a log-likelihood ratio *G*-test (Zar 1984).

In 1998, we captured and radiotagged 12 lactating female big brown bats to locate maternity roosts. We attached 0.53- to 0.78-g radiotransmitters (Holohil Systems Ltd., Carp, Ontario, Canada) that were <5% of body weight, as suggested for bat telemetry studies (Aldridge and Brigham 1988). We trimmed a small patch of fur in the interscapular region, where we attached transmitters using Skin-Bond adhesive (Smith and Nephew United, Inc., Largo, Fla.). We located roosts during the day from vehicles with roof-mounted antennas. We also opportunistically checked for signals of tagged bats foraging on RMA at night. Bat capture and tagging were approved under protocol 804.11, Institutional Animal Care and Use Committee, Midcontinent Ecological Science Center, and were authorized under Colorado Division of Wildlife permit TR-738.



Bat detector on stand at a sampling site.

Echolocation activity

Echolocation activity is used widely to index habitat use by bats (Furlonger et al. 1987, Thomas 1988, Humes et al. 1999, Jung et al. 1999). However, it does not provide a true estimate of abundance. Results are applied generally to comparisons of activity among habitats (Hayes 1997, Racey 1998) and in some cases to species identification (O'Farrell et al. 1999*b*). We measured echolocation activity at RMA from 19 June to 26 August 1997 using the Anabat II Bat Detector hardware and software system version 5.2b (Titley Electronics, Ballina, New South Wales, Australia) coupled with a laptop computer.

Habitat other than grassland at RMA occurred only in small patches (Hoff 1998). We therefore tested a null hypothesis of no differences in bat echolocation activity among habitats based on edge features. We considered presence of tree edge or water edge as "treatments" in a 2×2 factorial sampling design (Zar 1984) that allowed testing for interaction effects. To achieve the 2×2 factorial design, we sampled at sites categorized in 1 of 4 habitat edge types: no tree or water edge (open prairie), water edge only (prairie-water interface), tree edge only (prairie-tree interface), or tree-water interface.

We used aerial photographs to select a sampling frame of 24 possible sites (6 sites/category) that also met the following criteria: tree edges $\geq$50 m in length, tree heights $\geq$15 m, water present at the time of selection, low soil contamination from past industrial practices, $\geq$300 m from other possible sources of water, $\geq$300 m from other opposing structural features, and $\geq$300 m from other possible sampling stations. We then randomly selected 8 sites (2 sites/habitat edge category) from the pool of 24 possible sites to maximize number of replicate nights.

Availability of equipment and personnel limited simultaneous sampling to 2 sites/night, which likely minimized effects of temporal variation in bat activity (Hayes 1997). For each sampling night, we randomly selected a pair of sites to monitor (2 different edge types monitored/night), but selected only from sites not previously selected (sampling without replacement) until all sites had been monitored. We repeated this procedure to subsample each of the 8 sites on 3-4 nights each.

We counted bat passes as basic units of activity (Hayes 1997). We considered a bat pass to be a continuous series of $\geq$1 call notes with no pauses greater than 1 second between call notes. We sampled echolocation calls from stands placed at the site. The stand had a rotating arm that held the bat detector 2 m above ground at a 45° angle. We conducted acoustic sampling beginning 30 minutes after sunset in alternating 10-minute "on" and "off" periods for 90 minutes of "on" time. We used this sampling scheme to increase likelihood of independence of observations and to maximize the period when battery power was available for the laptop computer. During "on" periods, we rotated the detector clockwise 90° every 2.5 minutes to minimize observer and directional biases. We tallied all bat passes detected during "on" periods concurrent with sampling to circumvent potential recording equipment failure, with most calls also recorded on the hard drive of a laptop computer for future analysis. We used a 2-way factorial ANOVA (Zar 1984) design that tested for effects of tree edge, water edge, or their interaction on bat activity.

To compare relative abundance of species identified based on echolocation calls with capture records, we later identified the recorded bat passes to species or species groups. We based identification on qualitative comparison of call structures with those of hand-released bats recorded at RMA and with similar recordings from other western U.S. sites using the same hardware and software systems (L. Ellison, unpublished data; O'Farrell et al. 1999*b*). As in most other studies, we were able to identify calls of hoary bats (*Lasiurus cinereus*) and mouse-eared bats (*Myotis* spp.) based on qualitative aspects of echolocation call structure (Furlonger et al. 1987, Hickey and Neilson 1995, Barclay 1999, Humes et al. 1999). We combined counts of silver-haired (*Lasionycteris noctivagans*) and big brown bat (*Eptesicus fuscus*) passes into one category because these species can exhibit overlapping call characteristics (Betts 1998). We assumed that most of these calls were attributable to big brown bats because of their overwhelming dominance in our capture results and an expected absence of migratory silver-haired bats during the period in summer when we determined activity patterns. We reported proportion of calls attributable to these 3 groups based on total number of acoustic files stored to computer disk during activity sampling at all sites.

We also sampled bat echolocation calls opportunistically while tending mist nets. We did not use these results in our analysis except to note probable occurrence of one species.

Results

We captured 151 big brown bats (85.8%), 17 hoary bats (9.7%), and 8 silver-haired bats (4.5%). Proportion of adult females was greater than adult males in big brown bats (78.5%, $n=135$ with sex determined, $G_1=46.7$, $P<0.001$) and silver-haired bats (87.5%, $n=8$, $G_1=5.1$, $P<0.05$). Juvenile big brown bats ($n=12$) also were captured. Silver-haired bats were captured only in late spring and very early summer, and all were adult. Most ($n=12$) hoary bats were adult males (75%, $n=16$ with sex determined, $G_1=4.2$, $P<0.025$), but captures also included lactating females ($n=2$) taken 18 June 1998 and a juvenile captured 3 August 1998.

Eight of the 12 radiotagged big brown bats led us to 12 maternity colonies, all located in buildings in intensely urbanized areas 9.2–18.8 km south or southwest of points of capture at RMA ($\bar{x}=13.8$ km, SE=3.2 km). We did not discover any maternity colonies on the refuge. Two of the 12 tagged bats were never located and 2 others were detected feeding on the refuge but their roosts were not found. Despite limited efforts to track foraging bats, 8 of the 12 females returned to RMA to feed on $\geq$1 night.

Bat activity differed by habitat edge features ($F_{3,4}=18.0$, $P=0.009$). Water and tree-edge features contributed significantly to bat activity at a site ($F_{1,4}=9.49$, $P=0.0372$; $F_{1,4}=40.72$, $P=0.0031$), but the interaction of water and tree edge did not contribute significantly to bat activity ($F_{1,4}=3.8$, $P=0.122$). Activity was more than 5-fold greater at sites with tree and water edges than open prairie sites. We removed one night of sampling from analysis because we considered it to be a statistical outlier (we collected 244 bat passes on this night at a tree–water edge site, 4 times the mean of other nights in this category).

Of 955 bat passes saved to disk during acoustic sampling, 688 (72 %) were identifiable, with the remainder too fragmented to categorize. Identification of species based on echolocation calls during habitat-activity sampling was very similar to proportions taken in mist nets, with 67 identified as hoary bats (9.7%) and 618 identified as big brown or silver-haired bats combined (89.8%). However, 3 also were identified as *Myotis* spp. and 4 passes recorded during opportunistic sampling on 2 and 7 July 1997 were identified as red bats (*Lasiurus borealis*).

Discussion

The pattern of species richness and abundance we observed was predictable based on the simple character of the landscape and availability of roosts. On a macrogeographic scale, high bat species richness and evenness in temperate North America are associated with landscapes with topographic and structural complexities that can provide an array of potential roost sites (Humphrey 1975). Although 18 species of bats are known from Colorado (Fitzgerald et al. 1994), we detected only 5 species and one of these (the big brown bat) was disproportionately high in abundance. The high-plains urban environment near RMA offers only 2 types of roosts: few trees or snags and many buildings. Hoary bats, silver-haired bats, and red bats roost in trees, whereas big brown bats and some *Myotis* are known to roost in buildings (Barbour and Davis 1969). An abundance of big brown bats roosting in buildings may be a common feature of urban refuges. Our capture results are strikingly similar to findings from urban parklands near Detroit, Michigan, where big brown bats constituted 83% of captures (Kurta and Teramino 1992). Only 3 other species of bats (hoary, silver-haired, and red bats) were found in this other urban situation, all of which roost in trees (Barbour and Davis 1969).

Radiotelemetry results confirmed that big brown bats commuted to the refuge at night from buildings in the urban core of Denver. The mean distances from these urban roosts to RMA were 10 times greater than the 1- to 2-km distances to foraging areas typically determined or suggested for this species from other telemetry and natural history studies (Brigham and Fenton 1986, Kurta and Baker 1990, Brigham 1991), emphasizing the likely importance of the refuge as a feeding area for urban bats from much of the metropolitan area. The long commuting distances also illustrate the behavioral flexibility in roost and foraging site selection of big brown bats that has become evident from numerous studies (Geggie and Fenton 1985, Brigham and Fenton 1986, Brigham 1991). Big brown bats roosting in buildings in the small (population 50,000) city of Medicine Hat in the prairies of Alberta, Canada, also were reported to forage in outlying areas, some at greater distances from roosts than reported in other locations (Wilkinson and Barclay 1997). Buildings in core urban areas near RMA apparently provide roosts for big brown bats that are more suitable for maternity colonies than trees or snags on the refuge or buildings in nearby, newer suburban fringes of Denver.

Species identifications by echolocation call characteristics in the simple bat community at RMA corresponded with results from captures, in that a preponderance of big brown bats and a similar proportion of hoary bats were revealed by both techniques. However, echolocation detectors also documented the likely occasional use by at least 2 other species (red bats and *Myotis* spp.). Although reliability of identifying bat calls to the level of species can be controversial (Barclay 1999, O'Farrell et al. 1999*a*), this and other recent findings suggest that combining mist-net and bat-detector surveys is likely to reveal the greatest species richness of bats in a given area (Kuenzi and Morrison 1998, O'Farrell and Gannon 1999).

Our study suggests that urban wildlife refuges can provide important areas for bats, with species composition, richness, and evenness likely to be dictated in part by the range of available roosting opportunities. Sex ratios favoring adult females, use by juvenile big brown bats, and presence of female and young hoary bats in midsummer suggest that the RMA and perhaps other urban refuges may be important as feeding areas in support of reproduction and recruitment in local bat populations. The greater activity of bats at edge habitats at RMA, particularly trees along water, suggests that maintaining such features in otherwise structurally simple high-plains landscapes will provide more favorable conditions for bats. Although additional research specific to particular areas is needed, providing habitats suitable for foraging bats near urban areas appears to have promise as a conservation tool. Furthermore, developing bat conservation-oriented interpretation and education programs in urban refuges and parklands utilized by bats has potential to reach large numbers of people.

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M. O'Farrell reviewed the manuscript. J. Wimsatt, Colorado State University, was the consulting veterinarian.

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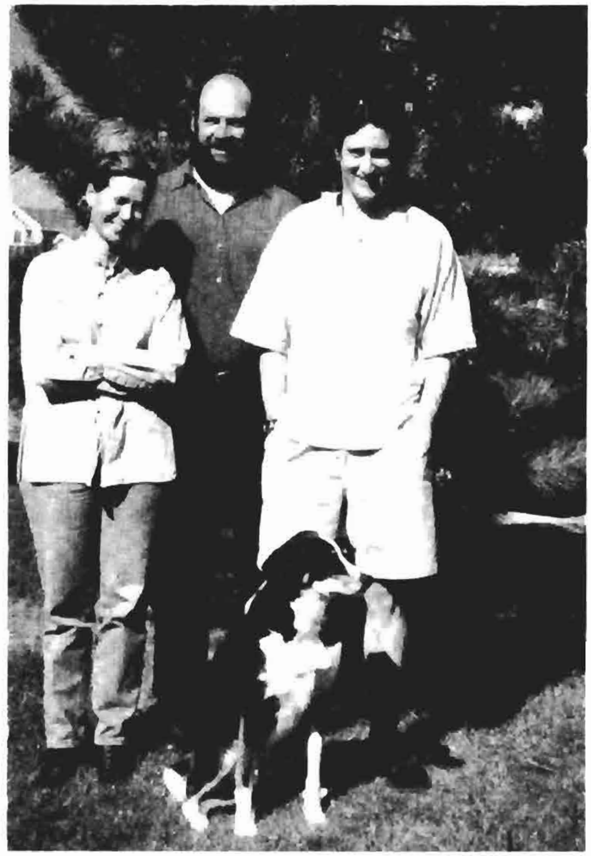

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