



ROOSTS AND NOCTURNAL MOVEMENTS OF LONG-NOSED
BATS (*LEPTONYCTERIS CURASOAE* AND *L. NIVALIS*) IN
SOUTHWESTERN NEW MEXICO

FINAL ADMINISTRATIVE REPORT

**Submitted to: Margie Guzman, Las Cruces District Office, Bureau of Land
Management, 1800 Marquess Street, Las Cruces, NM 88005-3370**

18 August 2006

**Prepared by: Michael A. Bogan and Paul M. Cryan,* U.S. Geological
Survey, Fort Collins Science Center, Arid Lands Field Station, Department
of Biology, University of New Mexico, Albuquerque, NM 87131 (*2150
Centre Ave, Bldg. C., Fort Collins, CO 80526), and Christa D. Weise,
Department of Biology, University of New Mexico, Albuquerque, NM 87131**



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EXECUTIVE SUMMARY

This report details the final component of a four-year study into the occurrence and biology of two endangered, nectar-feeding, long-nosed bats (*Leptonycteris curasoae* and *L. nivalis*) in southwestern New Mexico. The study was initiated during 2002 and first involved searching abandoned mines in the region for evidence of use by *Leptonycteris*. Internal surveys of over 280 mines conducted by Dr. J. Scott Altenbach in the 1990's revealed no sign of roosting by these species in the area. In 2002 and 2003, we examined 217 additional abandoned mine workings in the region, most on land overseen by the Bureau of Land Management; 79 of these sites provided potential roosting habitat for bats. Fifty-one of the 79 mines contained signs of use by several species of insectivorous bats. However, no signs (e.g., droppings or remains) of *Leptonycteris* were observed at any of the surveyed mines, despite similarities to mines occupied by these species in other regions (Sherwin et al. 2003).

In 2003, we conducted extensive netting in the "boot-heel" of New Mexico (Hidalgo Co.) and in adjacent southeastern Arizona to obtain information on seasonal occurrence and distribution of the two species of long-nosed bats in the region. We started netting on 20 May and ended our work on 12 October. We captured 290 bats of 17 species at 24 different sites, including *L. curasoae* in the Peloncillo Mountains and both species of *Leptonycteris* in the Animas Mountains. We tracked 6 radio-tagged *L. curasoae* in the Animas Mountains for a total of 29 nights during 2003, averaging about 4 nights of tracking per bat. One-way flight distances of these bats from their day roost varied from 5 to 14 km. Most were detected near the day roost and at a night roost 3.2 km to the north. One individual was tracked to the south of the day roost. In 2003 we were unable to triangulate instrumented bats. Long-nosed bats were present in the boot-heel from about mid-July to at least the end of August, and probably beyond that date. These results and a review of mine searches were provided to BLM in a verbal presentation in early 2004.

The study detailed in this report focuses on our efforts to follow the nighttime movements of *Leptonycteris* using radio telemetry during the summers of 2004 and 2005. In 2004, we spent approximately 275 person-days radio tracking bats. We captured 35 *L. curasoae* and 18 *L. nivalis* in the Animas Mountains and tagged 23 of them with miniaturized radio transmitters. Radio telemetry helped us find a new roost in Walnut Canyon in the Animas Mountains, which appeared to be used as both a day and night roost by small numbers of *Leptonycteris* of both species. Additionally, several "fixes" of instrumented bats led us to believe there was a large day roost in the Big Hatchet Mountains. Although our attempts to locate this new roost during the summer of 2004 were not successful, we tracked at least 7 different individuals to its suspected location during the early morning and away from there in the early evening. The two species appeared to be communally occupying both day and night roosts in the area. We made a presentation of our preliminary tracking results to BLM in early 2005.

In 2005, we again concentrated on radio-tagging, locating, and following bats. Long-nosed bats were moderately common where we worked in the Animas Mountains in 2005, although they appeared to arrive in the area later than in 2004. Both species of *Leptonycteris* continued to use the day roost in Pine Canyon and small numbers used the roost in Walnut Canyon that we discovered in 2004. Our capture efforts indicated that activity of *Leptonycteris* during the night was relatively high at Gibson Tank but seemed to be higher at the abandoned ranch house (OK Bar) that the bats used as a night roost. This structure is important to the bats but it continues to deteriorate because a new roof is badly needed. Analysis of our radio telemetry data from both 2004 and 2005 indicates that the Animas Mountains are important foraging grounds for *Leptonycteris* in the region. During the summer of 2005 we continued to observe tagged bats moving out of the Animas Mountains and across the Playas Valley; we eventually located a significant new day roost (a natural cave) in the Big Hatchet Mountains. All evidence indicates that this is the same roost used by the bats we tracked to the area during 2004. The newly discovered roost is the largest colony known to be comprised of both *L. curasoae* and *L. nivalis* in the United States. During September of 2005 we counted over 5,000 bats exiting from one of the two known entrances to this new roost. The roost in the Big Hatchet Mountains is over 30 km to the east of the Animas roosts and falls outside the known range of both species. The discovery of these additional roosts suggest that adequate roosting habitat for the two species in the region may be more common than was previously suggested by their known presence in a single day roost. Clearly, both species of *Leptonycteris* have more extensive ranges in southwestern New Mexico than was previously believed. Dates of occurrence in 2005 fell within the time period that *Leptonycteris* were previously known to occur in the area (mid-July to mid-September), a period that typically coincides with the peak flowering of *Agave* in the region. This report provides detailed information on the tracking of tagged bats during 2004 and 2005 and the new roost discovered in the Big Hatchet Mountains.

INTRODUCTION

Background

The status of pollinator species in the U.S.-Mexico borderlands has emerged as a critical issue because of the importance of pollinators to agriculture, biodiversity conservation, and ecosystem function. These pollinators have recently been highlighted in: a draft conservation strategy focused on pollinating birds, butterflies, and lesser long-nosed bats (Arizona-Sonora Desert Museum 1999); a review of pollinator issues and research and funding needs by the U.S. Departments of Interior and Agriculture (Tepedino and Ginsberg 2000); and a workshop on inventory and monitoring of bats that highlighted pollinators (O'Shea and Bogan 2003). Discussions during the latter workshop outlined several research and conservation needs regarding pollinating bats, including the need to conduct baseline inventories, initiate and continue roost exit counts, standardize counting methods, share data, and seek funding for research and

management. In the context of these concerns about pollinators, the general absence of current information on pollinating bats in New Mexico is critical. Thus, funding from the Bureau of Land Management (BLM) from 2002-2005 provided an excellent opportunity to initiate pre-emptive and high-priority studies of pollinators in the “boot-heel” region of New Mexico (Hidalgo Co. in the southwest corner of the state).

Three species of nectar- and pollen-feeding bats are unique among an otherwise insectivorous bat fauna in the Southwest, and are of critical importance to the health and maintenance of natural ecosystems in the borderland area. These three species (Mexican long-tongued bat, *Choeronycteris mexicana*, lesser long-nosed bat, *Leptonycteris curasoae*, and the greater long-nosed bat, *L. nivalis*) form a guild that migrates northward from southern Mexico in the spring and summer, perhaps along “nectar corridors” of flowering plants that provide a supply of nectar and pollen. In New Mexico, Texas, and Chihuahua, as far as is known, the bats depend exclusively on flowers of *Agave*; in Arizona and Sonora they also obtain nectar and pollen produced by flowers of columnar cacti. Most nectarivorous bats that occur in the U.S. borderlands during the early summer are believed to be females that are either pregnant or accompanied by young, implying that this area is important to reproduction and maintenance of viable populations.

Taxonomy

The nomenclature of long-nosed bats often has been unclear. The first species to be described was what is now known as *L. nivalis* (Saussure 1860) from Veracruz, Mexico. Then, in 1900, Miller (1900) described *L. curasoae* from the island of Curacao, Netherlands Antilles. In 1940, Martinez and Villa (1940) described what was then thought to be a subspecies of *L. nivalis*, *L. n. yerbabuenae* from Yerbabuena in the Mexican state of Guerrero. Subsequently, two more subspecies were described, *L. n. longala* (Stains 1957) from Coahuila, Mexico and *L. n. sanborni* (Hoffmeister 1957) from the Huachuca Mountains, Cochise County, Arizona. At present, many authorities believe that there are three species: *L. nivalis*, (a monotypic species with *longala* a junior synonym) from the United States, Mexico, and Guatemala; *L. curasoae* (*tarlosti* a junior synonym) from South America and the Caribbean; and *L. yerbabuenae* (*sanborni* a junior synonym) from the United States, Mexico, and south to Honduras and El Salvador (Wilson and Reeder 2005). It should be noted that much of the literature on *L. yerbabuenae* is found under the name *L. sanborni*. Also, not all authorities (e.g., Arita and Humphrey 1988) accept that there are three species and instead recognize only *L. nivalis* and *L. curasoae*; *yerbabuenae* is then recognized as a subspecies of *L. curasoae*. Indeed, this is the nomenclature used by the U.S. Fish and Wildlife Service in their documents regarding the endangered status of these species. In this report we follow the “last revisers” (Arita and Humphrey 1988) and use *L. nivalis* and *L. curasoae yerbabuenae* for the species occurring in New Mexico.

Status

The U. S. Fish and Wildlife Service (FWS) lists both *Leptonycteris curasoae* and *L. nivalis* as Endangered and formerly listed *C. mexicana* as a category 2 candidate for listing. Like many species of bats, these three species may be jeopardized by vandalism at roosting sites, destruction of roosts, loss of habitat and food resources, and direct killing by humans. There appears to be little, if any, federal funding currently directed at these species. Rudimentary monitoring exists for *L. curasoae* in Arizona and Mexico but efforts are separate and rarely standardized. Nonetheless, Fleming et al. (2003) believe that *L. curasoae* is neither uncommon nor declining and that the total population size of this species is orders of magnitude greater than estimates by Wilson (1985). In particular, there are very large maternity colonies of *L. curasoae* in southwestern Arizona and western Sonora (Fleming et al. 2003). Surveys of *L. nivalis* at the only known colony roost in the U.S. (Big Bend National Park in Texas) were not regularly conducted (Fleming et al. 2003) until recently (Ammerman 2006). The first survey for *C. mexicana* at historical locations in Arizona and New Mexico (Cryan and Bogan 2003) suggested that declines in this species were not obvious based on recurrences of bats at known historic roosts.

Distribution and Occurrence

As far as is known, New Mexico is unique among the southwestern states in having both species of *Leptonycteris* and *C. mexicana* all occur during the summer months. Only *L. curasoae* and *C. mexicana* occur in Arizona and in Texas only *L. nivalis* and *C. mexicana* are present. Nonetheless, even basic information on the distribution and abundance of *Leptonycteris* during the summer is poorly known in New Mexico. It has been speculated that *L. curasoae* in southeastern Arizona and southwestern New Mexico may use a migratory pathway along the flanks of the Sierra Madre Occidental to reach transient roosts in those states (Fleming et al. 2003; Wilkinson and Fleming 1996). Conversely, bats using the large maternity roosts in southwestern Arizona in late spring and early summer are thought to migrate north-westward along the coastal lowlands of western Mexico in spring. Later, some of these bats from western Arizona may move eastward into southeastern Arizona, and perhaps New Mexico, to areas where agaves are flowering (Cockrum 1991; Hoyt et al. 1994; Krebs et al. 2005). In any case, it appears that numbers vary from year to year, but whether this is in response to climate, plant phenology, or some other factor (in the U.S. or Mexico) is unknown. Likewise, arrival and departure dates may vary annually as well. Specimen records for New Mexico were taken between 17 July and 5 October; one female was lactating on 11 August (Findley et al 1975). Prior to this study, records were known only from the Animas and Peloncillo mountains. Dedicated efforts to locate *Leptonycteris* in New Mexico are needed to better understand the apparent variation in numbers and dates of occurrence.

Roosts

There is little information on the preferred roosting habitat of *Leptonycteris* in New Mexico. Most information on seasonal occurrence of these species in

New Mexico comes from records of bats that were netted or found while away from major day roosts. Specimens have been taken from several sites (Findley et al. 1975), such as a tunnel near Granite Pass in the Peloncillo Mountains, but none of those sites appeared to have major roosts. Prior to the current study we were aware of only one large “day roost” (Cockrum 1991), which is located in Pine Canyon in the Animas Mountains (J.S. Altenbach, personal communication). At least one “regional night roost” (sensu Cockrum 1991) at the OK Bar has been used over the years (Druecker 1966, Bogan, personal observations). However, within the range of long-nosed bats in New Mexico, it seems clear that long-nosed bats are not using abandoned mines (Sherwin et al. 2003). Because roosts are so poorly known in New Mexico, there have been no ongoing efforts to monitor trends in occurrence at such sites.

Foraging Habits

Little is known about food habits of *Leptonycteris* in New Mexico. The presence of these bats in New Mexico is almost certainly a result of seasonal flowering of *Agave* (Cockrum 1991; Fleming et al. 2003), especially *A. palmeri*, but the actual timing and intensity of this relationship has not been documented. Density, distribution, and status of *Agave* within the range of long-nosed bats in New Mexico are unknown. It also is not clear if long-nosed bats are using food plants other than *Agave palmeri* or somehow are supplementing their diet with other food sources (e.g., insects).

Objectives

We identified three high-priority research needs for *Leptonycteris* in New Mexico: 1) conduct cave and mine surveys for *Leptonycteris*; 2) study distribution, occurrence, population status, feeding ecology, movement patterns, and activities of *Leptonycteris*; and 3) assess the distribution, abundance, status, and phenology of known or potential food plants and the level of grazing by wildlife and domestic livestock on these plants. The results of the mine survey work were provided to BLM in spring of 2003 in a written report (Sherwin et al. 2003). Subsequent work by USGS has focused on the second objective and is reported herein. Progress on the third objective was contingent on additional funding to be sought by both BLM and USGS; this funding was never available. All work was conducted in Hidalgo County, NM, and emphasized the Animas, Big Hatchet, and Peloncillo mountains. All proposed work was consistent with recovery plans for both species of *Leptonycteris*.

Study area

This study was carried out during the summers of 2003-2005 in Hidalgo County, New Mexico. Initially, we worked primarily in the Animas Mountains and later expanded our work into the Playas Valley and Big Hatchet Mountains as we better discerned bat movements. The study area is approximately 38 km x 38 km or 1444 km² and is bounded by the following coordinates (Fig. 1): north - 108.60°, 31.70°; south -108.60°, 31.44°; east -108.33°, 31.56°; and west - 108.80°, 31.56°. We camped at New Well, about 3 km south of OK Bar along

Double Adobes Creek, on the Gray Ranch during both radiotracking sessions of 2004 and the first session of 2005. For the second session of 2005 we used Culbertson Camp at the south end of the Playas Valley. Most of our tracking activities were near or along Double Adobes Creek, Elephant Hill, and Walnut Canyon in the Animas Mountains and in the Playas Valley and western flank of the Big Hatchet Mountains, along Highway 81, which runs from Antelope Wells at the international border to Hachita, New Mexico.

Geology.--The Animas and Big Hatchet mountains and the intervening Playas Valley belong to the Basin and Range Region of western North America. Typically, the mountains are formed by uplift or volcanic action and are separated by alluvium-filled basins. Animas Mountain was formed during regional uplift and volcanism by several centers of eruption in the Miocene Epoch. These Miocene formations consist of combinations of quartz latite and rhyolite ashflows and some conglomerates (Wagner 1979). There apparently are no limestone or gypsum deposits in the Animas, unlike the Big Hatchet Mountains to the east that are characterized by limestone cliffs and slopes (Zeller 1965). During the late Pliocene and Pleistocene the area was characterized by large pluvial fresh-water lakes (e.g., Pleistocene Lake Cloverdale), but became saline as water levels dropped below outlet elevations. Some of these closed drainage basins, or playas, still flood ephemerally. The valley bottoms generally contain fine-textured alluvial deposits. Holmgren et al. (2003) found that vegetation in the Playas Valley became modern in character in just the last 10,000 yrs as piñon-juniper woodlands disappeared and more xeric oak-juniper communities became established.

Climate.--About 60% of the annual precipitation in the region occurs from July to September, mostly in the form of local thunderstorms that are part of the annual monsoon rains in the area; occasional rains occur in the winter months. The most arid season is late spring and early summer. Usually April, May, June, and November are the driest months whereas July, August, and September are the wettest. Although days can be hot in the summer, the elevation of much of the area tends to moderate the high temperatures. The average annual temperate range is from 13° to 21°C (Bourgeron et al. 1995). Temperatures are warmest in July and coldest in January (Cook 1986).

Vegetation.--Brand (1937) described the landscape of northwestern Chihuahua and Brown (1994) and coauthors (e.g., Pase and Brown 1994a, 1994b) provided overviews on biotic communities occurring in the Southwest and a map of these communities. Wagner (1979) and Cook (1986) described aspects of the vegetation of the Animas Mountains in particular. More recently, Bourgeron et al. (1995), in discussing the conservation value of the Gray Ranch, also provide vegetation classifications for the general area. We worked in several communities defined by Brown (1994). Upper elevations in the Animas (generally above where we worked) have small areas of Rocky Mountain (Petran) Montane Conifer Forest (ponderosa pine, aspen, and Douglas fir). Our

camp at New Well and many of our tracking stations in the Animas were in Madrean Evergreen Woodland (a mixture of alligator bark juniper, piñon, Chihuahua pine, and species of oak), the lower Interior Chaparral (manzanita, mountain mahogany), or Plains Grassland, such as south of OK Bar (grama and other grasses). Throughout the area are examples of Interior Southwest Riparian Deciduous Forest, such as sycamore (Double Adobes), cottonwood, and rabbit brush-Apache plume (north of OK Bar). In the Playas Valley, where we also had tracking stations, we were in Chihuahuan Desertscrub, with creosote bush and ocotillo on the bajadas and mesquite and saline-adapted shrubs on the alluvial floor of the valley.

Food plants for bats.--*Agave palmeri* is suspected of being the primary nectar and pollen resource for long-nosed bats in the boot-heel of New Mexico (Ober and Steidl 2004, Scott 2004). Therefore, we herein describe the distribution and general ecology of this important resource to *Leptonycteris*. *Agave palmeri* is a widely scattered plant of the oak woodlands and grama grasslands in the Southwest (Gentry 1982). It shows particularly good development on rocky slopes (often limestone) in the study area. Although *A. palmeri* was widespread throughout the study area, in our experience the densest "patches" often were on rocky, precipitous slopes, primarily in the Animas Mountains. We did not encounter dense stands of *Agave* anywhere we worked on the western flank of the Big Hatchet Mountains, although we know of a large population of *Agave* in the Little Hatchet Mountains.

Even though several species of *Agave* are suspected of being "keystone species" in many communities, few studies have been published regarding their pollination biology. Slauson (2000) provided an overview of current knowledge of pollination of *Agave* by examining such information as floral characteristics, known pollinators, and breeding systems. In particular, although paniculate agaves are assumed to have coevolved with nectar-feeding bats, few species of *Agave* appear to be strictly adapted to bats. Instead, Slauson believes that most agaves have floral characteristics that are general enough to attract multiple pollinators. Indeed, with specific reference to *A. palmeri*, Slauson (2000:18) stated that the relationship between this *Agave* and long-nosed bats "may be more accurately viewed as asymmetric: bats are dependent upon *A. palmeri* during their stay in southeastern Arizona [and presumably New Mexico], but agaves do not require bats for pollination." In Arizona, the range of *A. palmeri* extends northward beyond the documented range of long-nosed bats.

Threats to *Agave* or other potential food resources for bats have not been fully documented, although several management practices could affect them. Such practices include mechanical damage or removal of plants, fire (either intentional or wild), and grazing or browsing of stalks by cattle or wildlife. In an informal survey in New Mexico, Scott (1992) found that over half of the inflorescences of *Agave* that he studied had been damaged, in most cases by domestic cattle. He speculated that such a level of damage, if widespread, could be sufficient to compromise the seasonal occurrence of pollinating bats in parts of the Southwest. Widmer (2002) studied relationships between flower stalk

herbivory in *Agave palmeri* and livestock management in southern Arizona. Her results suggest the relationships between *Agave* and cattle are far from simple. She assessed herbivory of the flower stalks as a function of cattle stocking rate and timing of livestock use. Overall, the intensity of herbivory by cattle depended on a combination of annual precipitation rates and timing of livestock use, as well as distance of plants to water and timing of use. In areas with cattle present only during flower-stalk emergence the intensity of herbivory was related to an interaction between stocking rate and distance of plants to water.

Slauson (2002) studied the effects of fire on floral resources, fruit and seed set, and survivorship of *A. palmeri* in southeastern Arizona and southwestern New Mexico. In general, she found no significant differences in total nectar production, sugar concentration, standing pollen crops, or fruit and seed set between burned and unburned plants. Large amounts of nectar and pollen remained at dawn in both burned and unburned plants. Initial mortality across all size classes on one of three sites was only 3.3%. Among burned plants, those with greater damage (61-100%) tended to be less than 0.6 m in height and diameter. At least within the context of this study, fire did not appreciably decrease food resources of long-nosed bats or the survivorship of *A. palmeri*. This is partly explained by the rocky, low-fuel habitats preferred by this species as well as the morphology of the plant itself, which tends to protect the stored resources in the center of the plant.

MATERIALS AND METHODS

Bat captures

We netted bats at two sites in the Animas Mountains (Gibson Tank and OK Bar) where the occurrence of long-nosed bats has generally been predictable (Hoyt et al. 1994, J.S. Altenbach, personal communication). Bats were captured in mist nets placed near night roosts and in known flyways (Hoyt et al. 1994) using standard methods (Kunz and Kurta 1988). Netting did not occur in or near (< 500 m) roosts that were occupied by *Leptonycteris* during the day. Nets were monitored continuously and bats were removed immediately upon detection, placed in separate cloth bags, and kept in a quiet dark area until data were collected. Bats were usually held for less than 10 minutes, the exceptions being those held approximately 45 minutes for radio tagging. All bats were released unharmed as soon as data were collected. For each bat captured we recorded species, sex, age, weight, reproductive status, and any distinguishing marks (e.g., notched ears or nose leaf, noticeable scars or holes in wing membranes). Species of *Leptonycteris* were differentiated using 3 criteria (following Hoffmeister 1986, Hoyt et al. 1994, and our own observations): length of forearm, length of terminal phalanx of the 3rd finger, and length and density of fur. Bats were identified as *L. curasoae* if the forearm measured 52-56 mm, the terminal phalanx of the 3rd finger measured 9-15 mm, the pelage was relatively short and dense, and if there was no distinct margin of protruding hairs at the edge of the uropatagium. Bats were identified as *L. nivalis* if the forearm measured 52-60 mm, the terminal phalanx of the 3rd finger measured 17-19 mm, the pelage was

relatively long, and if there was a distinct fringe of hair along the edge of the uropatagium. We determined whether bats were adults or young-of-year by examining the back-lit finger joints of the wing. Bats exhibiting joints with translucent, cylindrical, cartilaginous epiphyses were classified as young-of-year whereas all others were considered adults (Richardson 1973). Because the joints of young bats ossify fairly quickly and the timing of our work was late in the summer, it is possible that some of the individuals we characterized as adults were young-of-year. We classified female bats as lactating if they exhibited bare pelage around the nipples and if milk could be expressed, postlactating if they had bare spots but no milk, and non-reproductive if the pelage around the nipples was complete (Racey 1988). Male bats were classified as reproductive if enlarged epididymes were observed (Racey 1988). Because we did not permanently mark bats, a remote possibility exists that a few of the individuals were sampled during both years. Body mass was determined with Pesola scales and external measurements were obtained with dial calipers while gently holding the bat in hand.

Radio telemetry

Select bats were marked for tracking using miniature radio transmitters tuned to a frequency of 164.XXXmHz (Holohil Systems Ltd., Woodlawn, Ontario; Blackburn Transmitters, Nacogdoches, Texas). Transmitters weighed between 0.53 - 0.78 g, which was always less than the recommended 5% of the bat's body weight (bats captured during the summer 2005 averaged about 25 g; Aldridge and Brigham 1988). Transmitters were attached to the mid-scapular region of the dorsal pelage using surgical adhesive (Skin-Bond, Smith & Nephew, Largo, Florida) after trimming a small patch of fur to within 1 mm of the skin. To ensure adhesion, bats were held for 30 minutes after transmitter attachment. Up to 14 bats were marked per 10-day tracking session (average = 12.5).

We continuously monitored for signals of marked bats from dusk to dawn using fixed telemetry stations. Stations were usually situated on mountain peaks or prominent topographic features, such as ridges and escarpments (Fig 1). Each station was operated by two people that alternated monitoring duties throughout the night. On a typical night, we operated between three and five stations. At each station, we tracked bats using a pole-mounted, 5-element Yagi antenna attached to a scanning telemetry receiver (R-1000, Communication Specialists, Inc., Orange, California). Antennae were mounted on top of 2-m poles set in a swiveling tripod base and the antennae elements were oriented parallel to the ground. Each pole was fitted with a mounted compass that allowed the tracker to take precise bearings on signal peaks without having to put down the antenna. In addition to tracking stations, we established a nightly base station that coordinated and facilitated all tracking activity. Tracking crews were in contact with each other and with the base station via two-way communication radios. Headphones were not used for tracking because they interfered with radio communication.

We used the following protocol for each night of tracking. After arriving at a tracking station, each member of the crew took bearings on between 3 and 6 “beacon” transmitters that we previously placed throughout the study area. Additionally, a global positioning system (GPS) was used to record the exact coordinates of the tracking station (± 5 -10 m). These bearings were called into the base station where they were checked against known bearings derived from cartographic software on a laptop computer. This step ensured that equipment was functioning properly each night and that tracking crews were taking accurate bearings. Tracking began shortly after sunset and consisted of continuously scanning active transmitter frequencies at 20-second intervals until contact with a transmitter signal was established. Immediately upon contact the tracking station that picked up the signal relayed the information (frequency and direction) to the base station and other tracking crews. From that point forward the other tracking stations tuned to the detected transmitter frequency and scanned for the signal. Any station that detected the signal would then take three simultaneous bearings at the start of every subsequent minute for three minutes. After three minutes of monitoring the detected signal, stations returned to scanning for other frequencies, unless directed otherwise by the base. Watches were synchronized regularly to ensure that bearings were simultaneous. Monitoring continued until dusk, with tracking crews typically alternating duties every 2 to 4 hours. Monitoring was suspended during periods of heavy rain, strong winds, and severe lightning, but continued when such episodes had passed.

Data analysis

We estimated bat locations from 2 or more simultaneous (± 5 sec) radio bearings. All locations were estimated using LOCATE II software and 95% error ellipses were generated using the accompanying software GIS.EXE (Nams 1990). We set the LOCATE II program to estimate locations based on 3 or more bearings using a Lenth Maximum Likelihood Estimation (MLE) technique (Lenth 1981a, 1981b; Nams and Boutin 1991). Locations derived from 2 bearings were estimated using a fixed standard deviation of 8.48° . This fixed deviation value was calculated from error estimates generated from the MLE analysis of all positions based on 3 or more bearings ($n = 661$) and using the following equation presented by Nams (1990):

$$\sqrt{\frac{\sum SS}{\sum (N - 1)}}$$

Where SS is the sum of squares from each location estimate and N is the sample size (number of bearings) for each location. We feel that this fixed error estimate was reasonable; average error of readings taken from beacons situated across the entire study area was 8.26° ($n = 176$).

For spatial analysis, location estimates derived using Locate II were incorporated into a geographic information system (GIS; ArcGIS 9.0, ESRI, Redlands, California). Tabular spatial data for the 95% error ellipses generated

by the program GIS.EXE were processed using a subroutine program for ArcGIS 9.0 (Loc2Shp_ArcGIS; available online at <http://arcscripts.esri.com/details.asp?dbid=14051>) that converted tabular data to polygons for use in the GIS. Spatial analyses were carried out on maps in the Albers Equal Area Conic USGS projection (NAD83 datum). Time of each location, by hour after sunset, was calculated using the sunset calculator of the U.S. Naval Observatory, Astrological Applications Department (available online at http://aa.usno.navy.mil/data/docs/RS_OneDay.html) with values derived for Lordsburg, NM, which is the city nearest the study area.

To investigate the temporal distribution of bat activity throughout the night, we divided the study area into three zones (Fig. 2). Analysis of bat activity within each zone was carried out using location estimates with error of $\leq 25 \text{ km}^2$. Although a spatial resolution of $\leq 25 \text{ km}^2$ means that the actual locations of some bats may have been in adjacent zones, we believe that such overlap is limited and that $\leq 25 \text{ km}^2$ is an appropriate resolution for studying course patterns of activity. We also plotted the relative density of location estimates throughout the study area as a means of better visualizing areas where we detected bats most frequently. A density map was created using the “density” feature of ArcGIS 6.0 (kernel method) and our telemetry location data with spatial error $\leq 25 \text{ km}^2$. This map is only intended for illustrating the areas where relatively high numbers of location estimates occurred, thus quantitative values (e.g., locations per km^2) are not provided.

Roost monitoring

We occasionally monitored day roosts for the diurnal presence of bats marked with radio transmitters or to count emerging bats at dusk. Day roosts were never entered during the months when bats were present (July-October). Monitoring for radio signals at roosts consisted of pointing antennae directly into roost openings or scanning outside of roost entrances for emerging bats at dusk. Roost counts consisted of one or more people visually observing the emergence of bats against a back-lit sky. We generally arrived at a roost 20 minutes before civil sunset and remained until we were certain that most bats had left the roost, generally from 2100 to 2300 hr. Species of *Leptonycteris* were differentiated from other species of bats exiting the roosts by their size and by the distinctive sound that their wings make during flight (a noise similar to the purring of a cat). The Mexican long-tongued bat is another species that occurs in the study area and has similar flight characteristics to *Leptonycteris*. We believe that *C. mexicana* was present in the roosts we monitored, but this species rarely occurs in numbers greater than 20 in a given roost (Cryan and Bogan 2003). Therefore, it is likely that *C. mexicana* only comprised a small fraction of the bats we counted emerging from day roosts.

Observers situated near roost entrances counted the number of bats seen exiting the roost and subtracted the number of bats seen re-entering the roost. *Leptonycteris* often return to a roost shortly after emergence or circle near the entrance and our methodology attempted to account for such activity. When possible, multiple observers made independent counts of emergences so that

variability of counts could be assessed. If more than several hundred bats exit a roost, visual counts alone are often not reliable. On several occasions during 2005, visual observations at roosts were supplemented with infrared video imaging. Infrared video cameras (TRV480, Sony Corp., Tokyo, Japan), with supplemental sources of infrared light (LED arrays--Wildlife Engineering, Tucson, Arizona) were set up outside of roosts and used to record emergence outflights. Tapes were later reviewed and counts were made from the video images. Video images were recorded on digital tape and then transferred to a computer hard drive via a portable storage device (GVD 8 Video Walkman, Sony Corp., Tokyo, Japan). Once transferred to the computer, emergences were played back in slow motion (Adobe Premiere, Adobe Systems Inc., San Diego, California) and precise counts were made.

We attempted to count exit flights from day roosts beginning in 2003 but more standardized counts were not possible until 2004 and especially the summer of 2005. Beginning in 2005 we conducted visual counts of bats leaving their day roosts approximately every two weeks from 21 June until 23 September. We monitored roosts at Cowboy Flats in the Peloncillo Mountains (T. Snow, D. Dalton, personal communications), Pine Canyon in the Animas, and the newly discovered roost in the Big Hatchet Mountains. Some exit counts were abandoned or delayed due to dangerous weather conditions.

We also attempted to monitor the general flowering status of *Agave* in the area of the three roosts during visits to those sites. We estimated the percentage of *Agaves* with stalks that were in bloom. Because species of *Agave* bloom from bottom to top and a single plant can be in flower for several weeks, we also assessed the stage of flowering by noting the position of open flowers within the inflorescence. We quantified the relative position of open flowers by noting their position within four vertical "quarters" of the inflorescence, running from bottom to top.

RESULTS

Bat captures

We captured 108 *Leptonycteris spp.* during the summers of 2003-2005 (Fig. 3; Appendix A). Most of these captures were made at the abandoned wolf-trapping cabin at OK Bar and around Gibson Tank, both on the Gray Ranch. This sample included 82 *L. curasoae* and 26 *L. nivalis*. Clear morphological differences were seen between the two species (see Hoyt et al. 1994 for *distinguishing characteristics*). For example, average forearm measurements for a representative sample of *L. curasoae* and *L. nivalis* that we captured were 53.9 mm (range 51.3 - 56.4; $n = 26$) and 57.1 (range 52.0 - 60.0; $n = 14$), respectively, and average length of the terminal phalanx of the 3rd finger was 12.6 mm (range 9.4 - 15.0) and 19.3 (17.9 - 23.0), respectively. We also used differences in the pelage and uropatagium to distinguish between the two species. Over all years, most of the *L. curasoae* that we captured were adult females and young-of-year, whereas most captures of *L. nivalis* were adult females and males that appeared to be adults (Fig. 3).

During our efforts to catch *Leptonycteris* over the years, we made incidental captures of 15 additional bat species that were previously known to occur in the region (Cook 1986; Findley et al. 1975). These species were the Mexican long-tongued bat (*C. mexicana*), southwestern myotis (*Myotis auricolus*), California myotis (*M. californicus*), western small-footed myotis (*M. ciliolabrum*), fringed myotis (*M. thysanodes*), cave myotis (*M. velifer*), long-legged myotis (*M. volans*), western pipistrelle (*Pipistrellus hesperus*), big brown bat (*Eptesicus fuscus*), silver-haired bat (*Lasionycteris noctivagans*), hoary bat (*Lasiurus cinereus*), western red bat (*L. blossevillii*), Townsend's big-eared bat (*Corynorhinus townsendii*), pallid bat (*Antrozous pallidus*), and Mexican free-tailed bat (*Tadarida brasiliensis*).

Radio telemetry

During the two years of intensive radio telemetry work (2004, 2005), 75% ($n = 27$) of the *L. curasoae* we captured were fitted with radio transmitters and 73% ($n = 19$) of the *L. nivalis* were tagged. We detected the signals of 72% ($n = 33$ of 46) of them on subsequent nights. We suspect that the 13 bats that we did not subsequently detect left the study area, their transmitters were lost, or the radios malfunctioned in some way. Four of the 7 *L. curasoae* that we "lost" were young-of-year bats, whereas 4 of the 6 *L. nivalis* that disappeared were postlactating adult females (the other 2 were an adult male and a young-of-year male).

Over 5000 person-hours of effort were spent tracking bats during the summers of 2004 and 2005, involving more than 300 hours of continuous tracking. Of the 5000+ bearings taken during tracking efforts, 4,837 were simultaneous with at least one other and were employed in the estimation of 1250 bat locations. We made 640 location estimates using 2 bearings and 656 locations were made using ≥ 3 bearings. The average number of bearings used per location estimate was 2.7. The size of error ellipses, which indicated the 95% confidence area of location estimates, were variable: 69% ($n = 900$) of estimates had error ellipses $\leq 100 \text{ km}^2$ (Fig. 4a); 60% ($n = 772$) had error ellipses $\leq 50 \text{ km}^2$ (Fig. 4b); 48% ($n = 627$) had error ellipses $\leq 25 \text{ km}^2$ (Fig. 4c); 33% ($n = 426$) had error ellipses $\leq 10 \text{ km}^2$ (Fig. 4d); and 13% ($n = 172$) had error ellipses $\leq 1 \text{ km}^2$ (Fig. 4e). Among estimates with error of $\leq 100 \text{ km}^2$, most locations for both species were made in the hours just after dusk and before dawn (Fig. 5). When examining the overall distribution of location estimates with error $\leq 100 \text{ km}^2$, there are no clear patterns between species (Fig. 6), sexes (Fig. 7), or age groups (Fig. 8). Unlike other reproductive groups, lactating females were rarely detected outside of the Animas Mountains (Fig. 9), but sample size was limited (locations from predominantly 2 individuals detected for 1-2 nights each).

Although we obtained a greater proportion of locations from the Playas Valley and Big Hatchet Mountains in 2005, the general patterns of distribution between years were similar (Fig. 10). Maps of the locations of individual bats, constructed using location estimates with error $\leq 100 \text{ km}^2$, are provided in Appendix B. In summary, these maps reveal that individual bats of both species regularly move between the Animas and Big Hatchet Mountains across the

Playas Valley. Sixty percent of the individuals of *L. curasoae* that we tracked were detected using both mountain ranges (Animas and Big Hatchets) of the study area, whereas only 15% of tracked *L. nivalis* occurred in all areas (Table 1, Fig. 11). Seventy-seven percent of the *L. nivalis* that we followed were detected in only one of the two mountain ranges and their adjacent plains (44% detected only in the Animas and adjacent plains, 23% detected only in the Big Hatchets and adjacent plains; Table 1, Fig. 11). Within species, there were no clear trends in the patterns of landscape use among demographic groups. A map of the relative density of location estimates made for both species during the study is shown in Figure 12.

Leptonycteris were detected more frequently in the Playas Valley during the hours after dusk and before dawn than during the middle of the night (Zone 2, Fig. 13). A similar, yet less distinct trend was observed in the Big Hatchet Mountains (Zone 3, Fig. 13). In contrast, overall frequency of detection in the Animas Mountains was higher during the middle of the night than in the hours just after dusk and preceding dawn (Zone 1, Fig. 13). Appendix C shows the distribution of all locations with error $\leq 1\text{km}^2$, by hour after sunset. Activity in the hours around dusk and dawn was concentrated near known day roosts, whereas location estimates from other hours of the night were more dispersed throughout both mountain ranges and the intervening plains (Appendix C).

Discovery of major new day roost

During the summer of 2004, several of the bats that we tracked left the Animas Mountains and traveled across the Playas Valley to the Big Hatchet Mountains. The radio signals of several of these individuals rapidly appeared and disappeared at dusk and dawn in the Big Hatchets, indicating that the bats were entering and leaving an underground roost (radio signals do not transmit through rock). In the last week of the 2004 field season we triangulated the general location of where the signals were appearing and disappearing, but we were not able to find a roost. Subsequent analysis of tracking data during the winter of 2004-2005 confirmed that both *L. curasoae* and *L. nivalis* signals were coming and going from the area of this suspected roost in the Big Hatchets during 2004. Bats tagged with radio transmitters during the summer of 2005 also moved between the Animas and Big Hatchets and we again triangulated signals disappearing and reappearing in the same general location as during the summer of 2004.

On 26 July 2005, we located a large fault cave that smelled strongly of *Leptonycteris* (a fruity and musky odor) in the vicinity of where the radio signals were appearing and disappearing. The signal of a bat then carrying an active radio transmitter was heard coming from deep within this cave. Subsequent observation of the cave exits at dusk confirmed that it is a major day roost for *Leptonycteris* (see *Roost monitoring* below). The general location of this roost is approximately XX km (by air) from Big Hatchet Peak at a bearing of XXX° (Fig. XX). We encountered two entrances to the cave. We consider the “main” entrance of the cave to be located at the north base of a large limestone block (XX.XXXX°N, -XXX.XXXXX°W). It has a near-vertical opening that measures

approximately 2 X 2 m. The cave mouth around this entrance is ringed by unstable rocks and boulders (Fig. 15). Another entrance is situated approximately 30 m ESE of the main entrance and is formed by a deep vertical crevice that runs approximately 20 m from NE (XX.XXXXX°N, -XXX.XXXXX°W) to SW (XX.XXXXX°N, -XXX.XXXXX°W). The NE side of this crevice is pictured in Figure 16. The upper parts of the crevice range up to 2 m in width. Although we were unable to take accurate measures of the depth of this crevice, we suspect that it is > 70 m deep (it took small pebbles approximately 4 seconds to hit the bottom).

Roost monitoring

We made a total of 20 counts at three roosts (generally excluding the Walnut Canyon roost) during the summer and early fall 2005 (Table 2). Our summaries of exit counts include data from the 8 counts made in 2004. Data for all counts conducted at the two major roosts (Pine Canyon and Big Hatchet) between 2003 and 2005 are consolidated by day of the year and depicted in Figure 17 to show seasonal trends in roost occupancy. Available data indicate that occupancy of these daytime roosts apparently peaks during the last half of August and the first half of September then dwindles by early October.

Cowboy Flats-- The two initial roost counts in mid- and late-June showed no signs of *Leptonycteris* in or around the roost. In addition to the exit count, roost entrances were examined and no signs of recent use by *Leptonycteris* were apparent (e.g., the presence of yellow "splat" [the syrup-like, pollen-filled droppings of nectar bats]). On 15 July we observed 4 *Leptonycteris* spp. exiting the roost, on 29 July approximately 21 *Leptonycteris* were seen emerging, and 37 bats left the roost on 10 August. By 28 August the roost appeared to be empty, although two to five *Leptonycteris* were seen and heard flying close to the entrance. On 11 September no activity in the vicinity of the roost was observed. There are no published data on the number of bats historically using this roost. The obvious presence of *Leptonycteris* in the vicinity in the early evening of 28 August suggests that there may be another roost nearby.

Pine Canyon-- As at Cowboy Flats, there was no evidence of long-nosed bats in the roost at Pine Canyon during visits in mid and late June. There was also no distinct smell of the bats at the roost early in the summer, although the odor was noticeable later in the summer when large numbers of bats were using the roost. On 16 July, 5 to 6 *Leptonycteris* were seen exiting the roost. On 28 July, 48 *Leptonycteris* were recorded, on 11 August we counted 277, and by 26 August the count increased to 858. The highest count during 2005 at this roost occurred on 10 September, when we observed 890 bats. By early October our observations indicated that *Leptonycteris* had left the roost. Adult and young-of-year of both species occupied this roost (as determined by radiotracking). In early September of 2004 we counted nearly 1400 long-nosed bats exiting this roost.

Big Hatchet Mountains-- The roost in the Big Hatchets was located in late July 2005 and thus surveyed only during the late summer. Radiotracking revealed that this roost was also used by both species of long-nosed bats, adults

and young-of-year alike. "Splat" marks were not observed at the roost exits, despite its occupancy by several thousand bats. However, the strong and distinctive odor of *Leptonycteris* was noticeable during and after use by the bats. The initial count at this roost was conducted on 27 July when both exits were monitored and we watched approximately 600 bats emerge. We abandoned an attempted count on 9 August due to extreme weather conditions (lightning and rain). We counted the greatest number of bats leaving this cave on 27 August, when 5443 bats were observed leaving the main entrance (the crevice entrance was not monitored). On 9 September both cave entrances were monitored and a total of 4912 bats were seen leaving the roost. On 23 September only 387 were counted and by mid October no *Leptonycteris* were detected leaving the roost.

Flowering of Agave

We observed that *Agave* began to flower near the roost at Cowboy Flats (on the west slope of the Peloncillo Mountains) in late June, and by mid July approximately 90% of the plants with stalks had begun to flower. About half of the plants were in the first quarter of flowering and half were in the second quarter. By early August nearly all agaves with flowering stalks were in bloom. Most were in their second and third quarter during early August and were still flowering by the end of the month. By the middle of September only a few plants were still blooming (95% were in the fourth quarter, some individuals in the third) and by late September no flowering *Agave* were observed at this site.

Flowering phenology of *Agave* in the Animas Mountains (near the Pine Canyon roost) and in the foothills of the Big Hatchets (near the Big Hatchet roost) was similar, but was generally later than in the Peloncillo Mountains. We estimated that flowering in the Animas and Big Hatchet mountains began about two weeks later than in the Peloncillo Mountains and by mid July only a few plants had begun to flower (all within in their first quarter). By late July the majority (85-90%) of the *Agave* with flowering stalks were in bloom. By the beginning of September less than half of the plants were still flowering (ca. 30% were in the third quarter, 70% in the fourth) and by late September we observed no active blooms. Overall, the flowering period in the Animas and Big Hatchet mountains appeared to be shorter than that observed in the Peloncillo Mountains during 2005. We subjectively estimated that this was true during 2004 as well.

DISCUSSION

Sympatric occurrence of two species of Leptonycteris.--Our results provide the most comprehensive picture available of roost use and nightly movement patterns by *Leptonycteris* in New Mexico. This study is unique in that it is the only research, to our knowledge, that focuses on the roosting and nightly activity patterns of *L. curasoae* and *L. nivalis* using the same sites. It is clear from the results of the netting, radio-telemetry, and roost-monitoring efforts that both species of *Leptonycteris* regularly occur in the boot-heel of New Mexico and exhibit similar roosting and nightly movement patterns when in the area. These

observations stand out from a general belief that *L. curasoae* and *L. nivalis* tend to live and forage in different habitats as a means of limiting competition.

Baker and Cockrum (1966) first pointed out that these species tend to be found in different habitats, with *L. curasoae* occurring more frequently at lower-elevation desert sites and *L. nivalis* occurring more often in higher-elevation forests dominated by pine and oak. Arita (1991) formally tested this hypothesis by analyzing the geographic distribution of occurrence records for both species in relation to patterns of climate and vegetation. Although his study did not find evidence of spatial segregation between the two species at broad geographic scales, significant differences were noted in the habitats used by each species. As suggested by previous authors, records of *L. nivalis* came from higher elevation sites with cooler mean annual temperatures that were more likely to be habitats with pine and oak or tropical deciduous forests, whereas records of *L. curasoae* were from lower-elevation sites with higher mean temperatures in tropical deciduous and thorn forests (Arita 1991). There are large areas where the ranges of *L. curasoae* and *L. nivalis* overlap (Arita 1991), but few, if any, studies have investigated the details of habitat use by both species in areas where they are sympatric.

Age and sex composition of samples.--Our capture samples indicate that the study area is occupied predominantly by adult female *L. curasoae* and their volant young, whereas relatively more adult males were observed among samples of *L. nivalis*. The greater proportion of adult male *L. nivalis* could be the result of sampling bias (fewer overall captures), our inability to precisely assess the age of bats, or true differences in the natural histories of each species. Age determination in live bats involves examining the degree of ossification in the wing joints and this can sometimes be problematic late in the summer. It is possible that some of the *L. nivalis* that we classified as adult males were actually older young-of-year with well developed wing joints. However, such systematic bias would mean that some *L. nivalis* were born earlier in the year or developed more rapidly than the other young *L. nivalis* and *L. curasoae* we observed. There is little available information to assess either of these possibilities. The greater proportion of male *L. nivalis* is likely due, in part, to species differences in patterns of dispersal or breeding activity during the late summer. Most of the *L. curasoae* that seasonally occupy Arizona and New Mexico during late summer are females and their young, although small groups of adult males occur in the Chiricahua Mountains of southeastern Arizona during early summer (Hayward and Cockrum 1971; Hinman 2003). Adult female *L. curasoae* and their young likely depart the U.S. borderlands during autumn and migrate back to northern parts of Mexico (Rojas-Martinez et al. 1999) where males occur throughout the year.

Origin of southwestern New Mexico Leptonycteris.--It has been hypothesized that *L. curasoae* occurring in southeastern Arizona and southwestern New Mexico during late summer are migrants dispersing north out of Mexico along the western flanks of the Sierra Madre Occidental (Fleming et al. 2003; Wilkinson

and Fleming 1996). Another hypothesis is that at least some of the *L. curasoae* occurring in this region during late summer are migrants from maternity colonies in southwestern Arizona and adjacent parts of Mexico (e.g., Pinacate Reserve). Supporting this hypothesis, Krebs et al. (2005) marked several female *L. curasoae* with radio transmitters at a maternity colony in Organ Pipe National Monument, southwestern Arizona, and subsequently detected two individuals in mountain ranges of southeastern Arizona, both more than 200 km southeast of where they were originally captured. Further, the timing of disappearance of *L. curasoae* from major roosts in southwestern parts of Arizona coincides with the seasonal appearance of females and young in our study area and at nearby sites in southeastern Arizona (Hinman 2003; Krebs et al. 2005). Cockrum (1991) postulated that after moving out of maternity colonies, *L. curasoae* expands its distribution to include higher-elevation areas where species of *Agave* are blooming during late summer. As pointed out by Hoyt et al. (1994), the presence of *L. curasoae* in our study area is consistent with this pattern.

Much less is known about the migration and movement patterns of *L. nivalis*. Only a single maternity colony of *L. nivalis* has been documented in Mexico (Moreno-Valdez et al. 2004) and none are known in the U.S. The Mexico colony, which contained as many as 3,500 bats during the summer of 1997, is located over 1000 km southeast of our study area in the Sierra Madre Oriental. Thus, the origins of individual *L. nivalis* that seasonally appear in the Animas and Big Hatchet mountains are unclear. The only other colony of this species known in the U.S. is in Mount Emory Cave, Big Bend National Park, Brewster Co., Texas. That colony is apparently comprised of adult females and young-of-year and is only known to occur there between the first week of June and the first week of August (Ammerman 2006; Easterla 1972). Counts of bats at the Mt. Emory cave are variable from year to year. This variation could be due to annual fluctuations in floral resources used by bats farther south in Mexico (Easterla 1972) or it may be simply the result of non-standard sampling methods (Ammerman 2006; Arita and Santos del Prado 1999).

It seems most likely that *L. nivalis* appears in southern New Mexico after dispersing north out of Mexico, perhaps along contiguous stretches of semidesert grasslands and Madrean evergreen forests that flank the eastern slope of the Sierra Madre Occidental range (see Brown 1994 for a general habitat map). It is also possible, yet less likely, that *L. nivalis* originating in the Sierra Madre Oriental region move into New Mexico from the east and south across patches of grassland and evergreen forests found on isolated mountain ranges. However, assessment of either potential migration route is currently limited to speculation due to a general lack of information on the occurrence of *L. nivalis* from the three Mexican states (Chihuahua, Coahuila, and Durango) south of where the species occurs in the U.S. (e.g., Fig. 1a of Arita 1991, see also Arita and Humphrey 1988). Hoyt et al. (1994) postulated that seasonal populations of *L. nivalis* may occur in the Sierra Madre Occidental between New Mexico and Sinaloa, Mexico, and we are inclined to agree with this assessment.

Exact patterns of migration remain to be discerned for both *L. curasoae* and *L. nivalis* (Arita and Santos del Prado 1999, Rojas-Martinez et al. 1999).

The continued uncertainty on migration pathways in *Leptonycteris* is disturbing considering that such migratory behavior and reliance on a seasonal plant makes these bats more susceptible to population decline (Arita and Santos del Prado 1999; Nabhan and Fleming 1993). In a conservation assessment of nectar-feeding bats in Mexico, Arita and Santos del Prado (1999) characterized *L. nivalis* as a widespread migratory species with small populations. Groups of *L. curasoae* that occur in the Animas and Big Hatchet mountains between mid-July and late-September could originate farther south in the Sierra Madre Occidental, farther west in the Sonoran Desert, or come from both regions. Regardless, we suspect that the two species of *Leptonycteris* that occur together in the study area in July through September utilize different regions of Mexico in other seasons.

Nocturnal movements of Leptonycteris.--Overall, we found little evidence of differences in nightly movement patterns between *L. nivalis* and *L. curasoae* in the study area (Fig. 6). We did not observe any consistent differences in nightly activity between bat species, sex, age, or any combination of these groups. The few lactating females that we tracked were not detected making extensive movements out of the Animas Mountains. This could be due to decreased foraging distance because of increased energy demands associated with lactation (Racey and Speakman 1987) or simply due to error from sampling so few individuals in this condition.

Our tracking results indicate that most flight activity of both species during late summer generally falls into two categories: concentrated movements in the Animas Mountains and more-dispersed movement across the Playas Valley along what is apparently a commuting route between the two major day roosts (Fig. 12). Although it is possible that bat activity went undetected in other parts of the study area, such as the western slope of the Animas Mountains or the eastern slope of the Big Hatchet Mountains, we occasionally monitored these areas for the signals of tagged bats, with little success. In the Animas Mountains, activity was generally concentrated along the valley surrounding Double Adobes Creek (Fig. 12). We detected bats using the Big Hatchet Mountains less frequently, although this could be due in part to sample bias, because all of the bats we radio tracked were captured at night (and presumably during or between foraging bouts) in the Animas Mountains. Thus, the bats we followed may have preferred foraging in the Animas, despite the fact that many roosted in the Big Hatchet Mountains on a regular basis. Alternatively, the Animas Mountains provide the greatest extent of habitat suitable for *Agave palmeri* in the study area, potentially making the Animas a preferred foraging ground for *Leptonycteris* that roost in smaller nearby mountain ranges. On several occasions we followed the movements of individual bats as they returned to the roost in the Big Hatchets during the morning and they typically flew directly across the Playas Valley from the Animas just before entering the roost. On no occasion during the times that we tracked bats coming and going from the roost in the Big Hatchets did we see evidence of extensive foraging (e.g., > 1 hour) in the Big Hatchet Mountains. Future efforts to track bats caught at or near the

roost in the Big Hatchets may provide a clearer picture of the proportion using that range versus the Animas. Another source of sampling bias in our study may be due to our general inability to have tracking stations in both the Animas Mountains and Playas Valley. In general, we were forced to choose one area or the other on any given night. Nonetheless, our results suggest that was not a major source of bias.

Agave palmeri is sparsely distributed in the Playas Valley compared to the surrounding foothills and mountain ranges. This scarcity of *Agave* in the plains, in conjunction with the linear distribution of telemetry locations across the valley between the two day roosts, leads us to believe that most of the activity we detected in the Playas Valley was associated with bats commuting to and from the major roost in the Big Hatchet Mountains. This hypothetical pattern of activity is also supported by the predominance of early-morning and early-evening telemetry locations from the Playas Valley—indicative of bats coming and going from their day roost to foraging grounds (Fig. 13; Appendix C). Although less dramatic, the trend toward fewer locations from the Big Hatchet Mountains during the middle of the night also indicates that extensive foraging may not occur there (Fig. 13; Appendix C).

For both species, we acquired a greater proportion of locations in the early evening and near morning (Fig. 5). This pattern can be the result of greater bat activity during the early evening and morning or differences in our ability to detect bats at different times of night. In the Animas Mountains, we regularly observed both species night roosting in the stone cabin at OK Bar during the hours around midnight, and in other regions, *L. curasoae* is known to night roost for extended periods (Horner et al. 1998; Ober 2000). It is likely that some of the variation in the number of telemetry locations by time of night was the result of bats roosting in inaccessible night roosts. Because radio signals are greatly attenuated by rock and other solid structures used as night roosts, disappearance of bats during the night into night roosts is a possibility. Another explanation for the lack of locations during the middle of the night is that the bats left the area in which we were able to detect them. We believe that this scenario is less likely, because we saw no consistent pattern of bats leaving our study area during the early hours of the night.

Leptoncyteris curasoae shows morphological characteristics (e.g., relatively high wing loading and large body size) of a species adapted for regular long-distance flights (Sahley et al. 1993). Indeed, Sahley et al. (1993) measured nightly commuting flights of 25-30 km with an average of 27.2 km during one-way commutes to foraging areas; mean air speed was 8.2 m/s. Studies of *L. curasoae* in other areas have shown nightly movements of similar distance and nature to those observed in our study. In the Sonoran Desert of Mexico, Horner et al. (1998) tracked the movements of female *L. curasoae* as they foraged on the seasonal blooms of columnar cactus. They found that reproductive females regularly commuted 30-35 km from their day roost to foraging areas and that bats generally used the same small (about 1 km² per night) foraging areas night after night. In that study, the bats regularly night roosted in close proximity to foraging areas, although they occasionally used night roosts farther away. Most

observations of *L. curasoae* in direct flight were made as bats were moving from day roosts to foraging areas, whereas flight in foraging areas was characterized by a more erratic path (Horner et al. 1998).

Foraging of Leptonycteris.--In southeastern Arizona, Ober (2000) tracked the nightly movements of 37 *L. curasoae* as they fed on *A. palmeri* and found individuals commuting about 19 km per night from their day roosts to foraging areas. In that study, bats ranged over areas as large as 5258 ha, but core-use areas (likely foraging areas) averaged less than 20 ha. Bats regularly used the same foraging areas, but sometimes changed foraging grounds when local flowers stopped producing nectar (Ober 2000). Although differences in the areas covered by foraging bats did not change with annual differences in density of flowering *A. palmeri*, *L. curasoae* left the roost earlier in the evening during a year of lower resource availability (Ober 2000). Tracking studies of *L. curasoae* in both Arizona and the Sonoran Desert of Mexico both indicate that this species typically visits the same foraging areas night after night and visits night roosts that are within or near foraging areas (Horner et al. 1998; Ober 2000). Although we only occasionally observed bats in the same areas from night to night, the distribution of night roosts used by bats during this study suggests that the Animas Mountains was a major foraging area for bats roosting in both the Animas and Big Hatchets. In light of the results from Sonora and Arizona, it is not implausible that the bats we tracked from the roost in the Big Hatchet Mountains do not forage in the vicinity of that roost, but rather commute > 20km to more productive foraging grounds in the Animas.

In the Sonoran Desert, evidence indicated that *L. curasoae* spent much of the early evening assessing the availability of columnar cactus flowers and did not begin feeding in earnest until nectar volume of these flowers reached a threshold value between midnight and 0200 (Horner et al. 1998). However, the timing of nectar production by *A. palmeri* differs from the columnar cactus observed by Horner et al. (1998), with peak nectar production occurring in the early evening (~2100) and then declining throughout the night (Slauson 2000). In our study area, we do not think that active feeding on nectar of *Agave* by *Leptonycteris spp.* was delayed until midnight, because we regularly captured bats covered with pollen at OK Bar and Gibson Tank well before that time. It is possible that the arrival of *L. curasoae* and *L. nivalis* to the study area during the later phases of flowering by *A. palmeri* (Scott 2004) is somehow related to nectar production and increased foraging efficiency.

Evidence suggests that in mainland populations of *L. curasoae*, diet is heavily comprised of cactus and species of *Agave* during the summer months (Fleming et al. 1993). Migratory *L. curasoae* may follow a "nectar corridor" of sequentially blooming cactus and *Agave* (Fleming et al. 1993). Limited evidence from analysis of stable nitrogen isotopes hints at the possibility of *L. curasoae* supplementing its diet during lean times of year with insect food (Ceballos et al. 1997). In the Chiricahua Mountains of southeastern Arizona, Hinman (2003) found insect fragments in the feces of 86% of the *L. curasoae* she sampled ($n = 76$) and she suggested that intake of insects may be more than incidental.

During our study, we gathered evidence that species of *Leptonycteris* may be foraging on insects to a greater degree than has previously been documented. While visiting the inside of the roost in Pine Canyon during spring of 2003 (bats were not present), we found a large pile of droppings that resembled the guano of insectivorous bats, yet was encased in what looked like the typical excrement of *Leptonycteris* (syrupy and yellow with pollen). This pile was directly beneath where we suspect *Leptonycteris* roosts in the cave. Analysis of these droppings, as well as additional samples found on drop cloths and walls in the night roost at OK Bar, revealed that the insect remains forming the guano pellets were entirely coated on all sides with pollen grains. Such high proportions of insect remains in droppings of *Leptonycteris* have not been reported from elsewhere in the range of either species and may be unique to the region. This evidence suggests that species of *Leptonycteris* in the boot-heel may seasonally supplement their diet with insect prey to a greater degree than in other places.

There has been speculation that long-nosed bats may forage in groups (Howell 1979) although some recent studies appeared to find little evidence of this. Fleming et al. (1998) studied behavior in roosting *L. curasoae* in western Arizona for two weeks late in the nursing period. Between 2000 h and 0330 h females nursed for an average of two times and a total of 52 minutes. Females appeared to move independently throughout the night. Between 0500 and 1900 h adults nursed young but seldom interacted with other females and no cooperative behavior was observed. Scott (2004:430), who made nocturnal observations at agave plants, noted that usually “only 1 bat was seen at a time, but sometimes there were 2.” Although we did not observe the bats at food resources, our tracking data provides no indication that any of the bats we followed were foraging together in groups.

The seasonal peak in counts at the roosts we monitored coincides with other reports of *Leptonycteris* appearing in the area in relatively large numbers and likely has to do with the local flowering of *Agave*. Based on observations of flowering *Agave palmeri* in the Peloncillo and Chiricahua mountains of southeastern Arizona and southwestern New Mexico, Scott (2004) observed that nectar-feeding bats (presumably *L. curasoae* and *C. mexicana*) did not appear at flowers in large numbers until late in the summer (24 August to 12 September) and were not evident for more than half of the early flowering period of *A. palmeri* (15 June to 12 August). That this also may be true in the Animas is suggested by the data of Hoyt et al. (1994), who netted as many as 200 *Leptonycteris* spp. near the day roost in Pine Canyon during this same time of year (August 26).

Work of Moreno-Valdez et al. (2004) showed a close relationship between abundance of *Leptonycteris* and agaves. They studied the relationship between population dynamics of *L. nivalis* at the only known maternity roost in Mexico and local biotic and abiotic factors, including density of flowering *Agave*. Abundance of greater long-nosed bats at the roosting site (El Infierno Cave) was correlated with the frequency of blooming agave and with ambient temperature. Other measures (e.g., cave temperature, humidity, and external humidity) were not correlated with the number of bats present. Potential factors that influence the migration of *L. nivalis*, such as the flowering phenology of food plants, were

modeled by Moreno-Valdez et al. (2000) and the results of that study could offer insight into future field studies of migration in this species.

CONCLUSIONS AND RECOMMENDATIONS

1. Protect known roosts.--Our tracking efforts confirmed that *L. nivalis* regularly shares a previously known day roost with *L. curasoae* in the Animas Mountains, as well as in a newly discovered day roost in the Big Hatchet Mountains. To our knowledge, these are the only two sites that are known to be occupied by both species during the day. Given the unique co-occurrence of two endangered species in these roosts and the fact that there are now more known roosts of *L. nivalis* in New Mexico than in any other state in the U.S., it is critical that these important sites be well protected. In particular, thought should be given to assuring that the roosts and areas around them remain undisturbed during the times that bats are present. It seems unlikely that humans could routinely enter either roost, given their vertical configuration, although several colleagues have expressed concern over disturbance created by illegal aliens during their passages through the area. More reasonably, we suggest that management authorities limit habitat modification activities and restrict any such activities to times of the year when bats are absent.

2. Continue monitoring bats at roosts.--It is important to assess the extent of variation in numbers at the two major roosts. Counts both in Arizona and Texas demonstrate variation, some of it considerable, and management agencies should develop a schedule of standardized counts to capture annual variation (i.e., was the 2005 count the tip of the iceberg?). Future monitoring efforts at these roosts should also measure density of blooming *Agave*. To accurately assess visitation rates of *Agave* it is crucial to also monitor known roosts, so that bat activity can be correlated with seasonal presence in the area (Scott 2004). Fluctuations in colony size make timing of visits crucial (Ceballos et al. 1997).

3. Continue searches for additional roosts or foraging areas.--All currently known large day roosts in New Mexico are natural caves or crevices, in contrast to Arizona where some of the major day roosts are abandoned mines. Although previous work and an earlier component of this study failed to find evidence of use of mines by species of *Leptonycteris*, bats captured at or near the Big Hatchet roost should be radiotagged to see if they are commuting to areas other than the Animas to forage or roost.

4. Stabilize the OK Bar Cabin.--This rock building likely serves as an important regional night roost and has a history of occupation by *Leptonycteris* of over 40 years. It is likely important to bats for a variety of reasons. This building is badly in need of renovation and stabilization. In particular the roof and joists need replacing and some minor stabilization of the walls should be done.

5. *Foraging and pollination studies.*--This study has generated considerable information on locations of bats in the Big Hatchet and Animas mountains and the Playas Valley between them. These locations and/or the error ellipses around them should be studied to determine if they are coincident with patches of *Agave*. If so, the patches themselves should be described with respect to density of plants, density of flowering (stalked) plants, and the like. Monitoring of patches that seem to be desirable would provide useful information on foraging activities of the bats. It also would be informative to conduct pollination studies on agaves in the area to determine the actual role played by bats. Finally, we encourage caution in the extent to which perceived impacts to agaves are used in the development of management plans. Although some information exists on impacts of fires on agaves, we do not believe that sufficient peer-reviewed information exists on the impacts of grazing or browsing of agaves by wildlife or livestock and any subsequent impact on long-nosed bats.

6. *Learn more about Big Hatchet roost.*--Information is needed on the physical structure and internal characteristics (size, evidence of past use, fossil remains, guano samples for diet analysis) of the cave. In addition, information on bats using the cave are needed, including demographics (species, sex, age); behavior (mating site), evidence of past use (ancient remains, guano deposits), and geographic origins of occupants (Texas, Arizona, Mexico). Fleming et al. (1998) placed remotely operated infrared cameras inside a mine during summer in southwestern Arizona to study the roosting behavior of *L. curasoae*. This work revealed valuable information on the activities and social behaviors of *L. curasoae* and similar methods used in the New Mexico roosts could offer important information on the interaction between *L. curasoae* and *L. nivalis* in this area of sympatry.

7. *Exercise caution with wind power development.*--Recent trends indicate that bats are particularly susceptible to mortality at wind turbines, with kills at some sites exceeding 500 bats over the course of just a few weeks (Johnson 2005), Migratory species of bats comprise the vast majority of individuals that are dying at turbines. Although we are not aware of any existing wind-energy facilities within the range of *Leptonycteris* within the U.S. or Mexico, long-nosed bats share many similarities with other bat species that are being killed by turbines elsewhere (e.g., long-distance migration, fast and strong flight) and such characteristics might make them susceptible as well. If the construction of wind turbines is proposed in the boot-heel of New Mexico, land managers in the region should consider the high risk that turbines may negatively impact *Leptonycteris* in the region.

ACKNOWLEDGMENTS

Funding for this study was provided by the Las Cruces Field Office of the Bureau of Land Management and the Fort Collins Science Center of U. S. Geological Survey. New Mexico Department of Game and Fish helped fund the

roost counts in 2005. Access to study areas was provided by the Animas Foundation/Diamond A Ranch, William Hurt; William and Philip Young, William McDonald, and the Coronado National Forest, USFS. We especially appreciate the important contributions in support of the study that were made by Rick Sherwin, Scott Altenbach, Dave Dalton, Sandy Wolf, Ben Brown, Jennifer Medina, and Rodrigo Medellín. At the BLM LCFO, we appreciate the assistance of Bill Merhege, Jack Barnitz, Margie Guzman, Ray Lister, and Jim McCormick. Thanks to Lyle Lewis of the USFWS New Mexico Ecological Services Field Office for technical support and joining us in the field.

For assistance in the field, often under trying circumstances, we appreciate the efforts of: Diana Alba, Alice Chung-MacCoubrey, Dayna Dominguez, Angela England, Jeff Frederick, Keith Geluso, Tania Gonzalez, Larisa Harding, Justin Hoffman, Robin Ives, Rachel Jankowicz, Russell Ligon, Gabriela Lopez, Jeff Mink, Tony Mollhagen, Regena Orr, Teri Orr, Cindy Ramotnik, Roger Rodriguez, Samuel Skalak, Jim Stewart, Karla Toledo, and Ernie Valdez. Field crews often sought nourishment at the Panther Tracks Café in Animas and we appreciate the early hours and patience of the staff there.

Thanks to Vilis O. Nams for developing Locate II as public domain software and to Brian R. Mitchell for help with the program used to convert tabular ellipse data into files for use in a GIS. Tom O'Shea and Laura Ellison provided useful comments on an earlier draft of this manuscript.

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Table 1. Tally of the general regions of the study area where individual bats ($n = 33$) were detected during the period they were tracked. Tabulated by species, sex, age, and reproductive class: M = male; F = female; NR = no signs of reproduction; Y = young-of-year; L = lactating; PL = postlactating. The three distinct regions of the study area were the Animas Mountains, Playas Valley, and Big Hatchet Mountains. See Fig. 1 for layout of study area. Numbers in parentheses in the column “All Areas” indicate the number of bats detected in all 3 areas on the same night.

Species	Group	Animas Only	Animas/ Playas	Playas Only	Big Hatchets/ Playas	Big Hatchets Only	All Areas
<i>L. curasoae</i> ($n = 20$)	M (NR)	-	-	-	-	-	1
	M (Y)	-	2	-	-	-	-
	F (NR)	-	-	-	-	-	3 (3)
	F (L)	-	1	-	-	-	1
	F (PL)	-	2	-	-	-	4 (3)
	F (Y)	-	1	1	1	1	3
<i>L. nivalis</i> ($n = 13$)	M (NR)	2	-	-	-	3	1
	F (NR)	1	-	-	-	-	-
	F (L)	1	-	-	-	-	-
	F (PL)	2	1	1	-	-	1

Table 2. Number of *Leptonycteris spp.* counted emerging from roosts at dusk during the summers of 2003 through 2005. See text for descriptions and locations of roosts. Numbers in parentheses indicate counts made after reviewing video images of emergences; all other values are based on counts made by observers. The count for the Big Hatchet roost on 8/27/05 (marked with an asterisk) only involved bats exiting from the main entrance and not the crevice entrance.

Year	Day	Pine Canyon	Cowboy Flats	Big Hatchet	All Roosts
2003	06/17/03	0	-	-	0
	08/27/03	500	-	-	500
	09/18/03	8	-	-	8
2004	06/22/04	3	-	-	3
	06/26/04	-	3	-	3
	07/05/04	11-14	-	-	11
	07/12/04	18	-	-	18
	09/02/04	1378	-	-	1378
	09/17/04	151	-	-	151
	09/18/04	43	-	-	43
2005	06/21/05	-	0	-	0
	06/22/05	0	-	-	0
	06/29/05	-	0	-	0
	06/30/05	0	-	-	0
	07/15/05	3-4 (4)	-	-	4
	07/16/05	5-6 (5)	-	-	5
	07/27/05	-	-	600	600
	07/28/05	48	-	-	48
	07/29/05	-	18-28 (21)	-	21
	08/10/05	-	37	-	37
	08/11/05	277	-	-	277
	08/26/05	811 (858)	-	-	858
	08/27/05	-	-	5030 (5443)*	5443
	08/28/05	-	0	-	0
	09/09/05	-	-	4784 (4912)	4912
	09/10/05	890	-	-	890
	09/11/05	-	0	-	0
09/23/05	-	-	375 (387)	387	
10/08/05	0	-	-	0	

Figure 1. Map of study area in Hidalgo Co., New Mexico, showing the location of telemetry stations (blue triangles) from which radio tracking was conducted during the summers of 2004 and 2005.

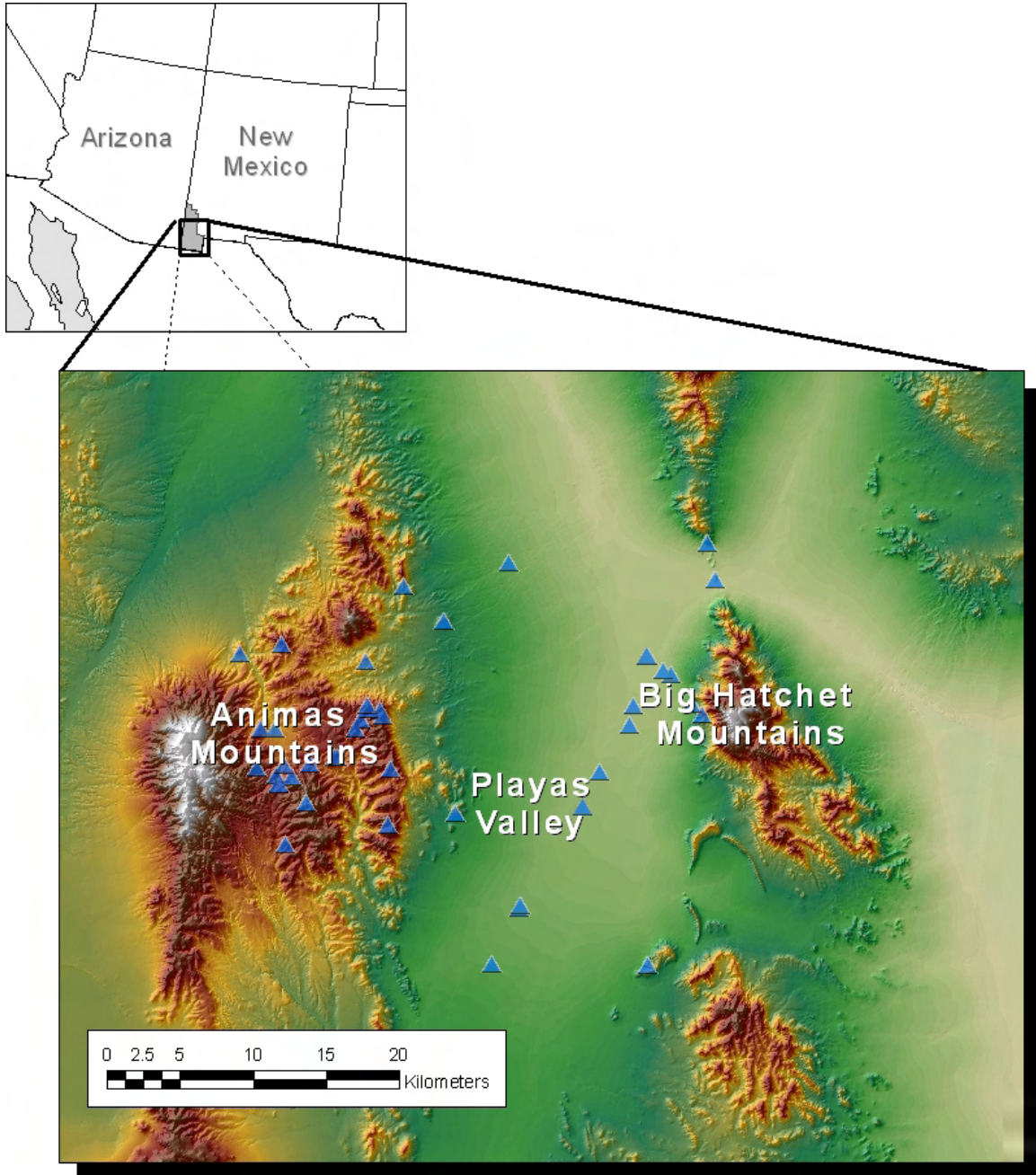


Figure 2. Zones delineated in study area to investigate the temporal distribution of bat activity throughout the night.

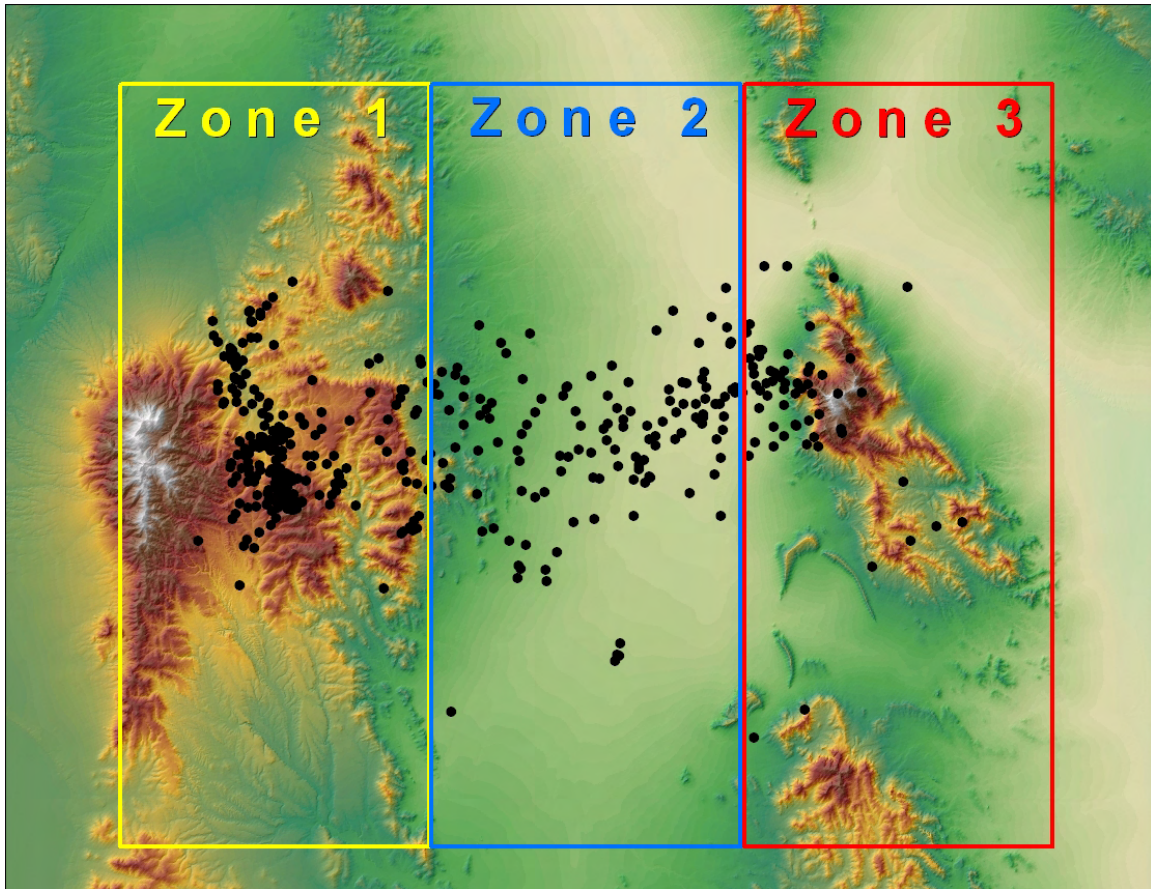


Figure 3. Number of *Leptonycteris* captured in the study area during the summers of 2003 through 2005, by age group, sex, and species. Solid bars represent *L. curasoae* and striped bars represent *L. nivalis*. See methods section for description of how age classes were determined.

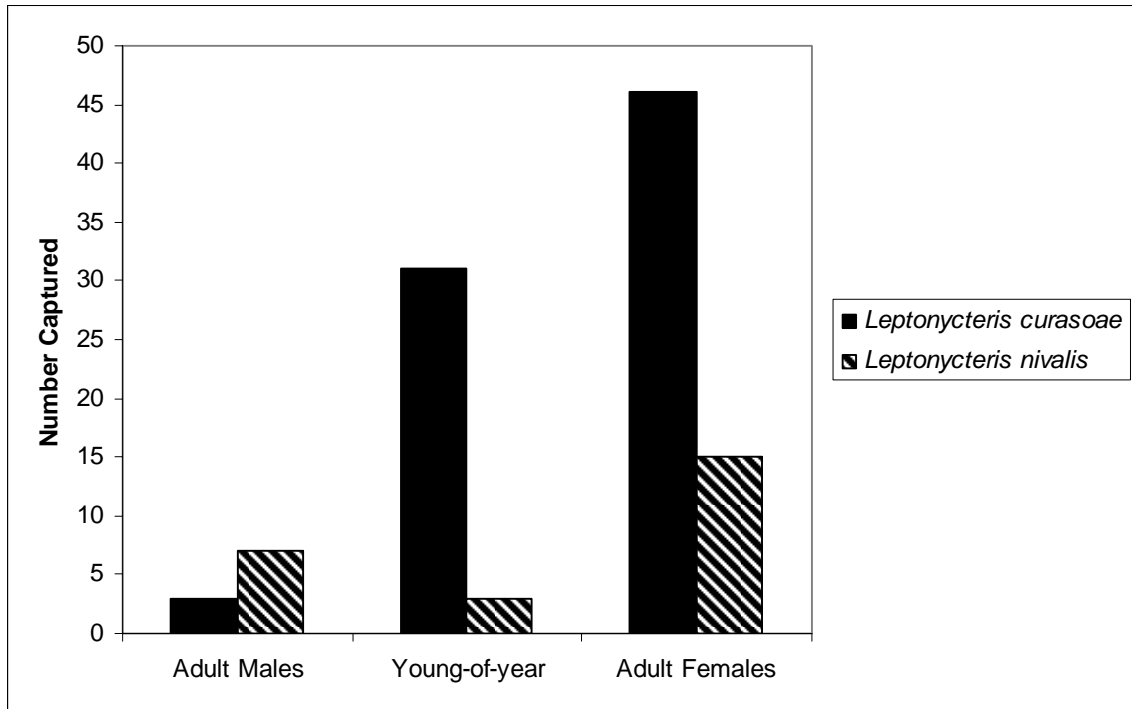


Figure 4. Locations of *Leptonycteris* estimated from radio telemetry data collected during the summers of 2004 and 2005. Points represent estimated location and surrounding ellipses represent 95% confidence areas for each location. Panels display different levels of error: **a)** error areas $\leq 100 \text{ km}^2$; **b)** $\leq 50 \text{ km}^2$; **c)** $\leq 25 \text{ km}^2$; **d)** $\leq 10 \text{ km}^2$; **e)** $\leq 1 \text{ km}^2$.

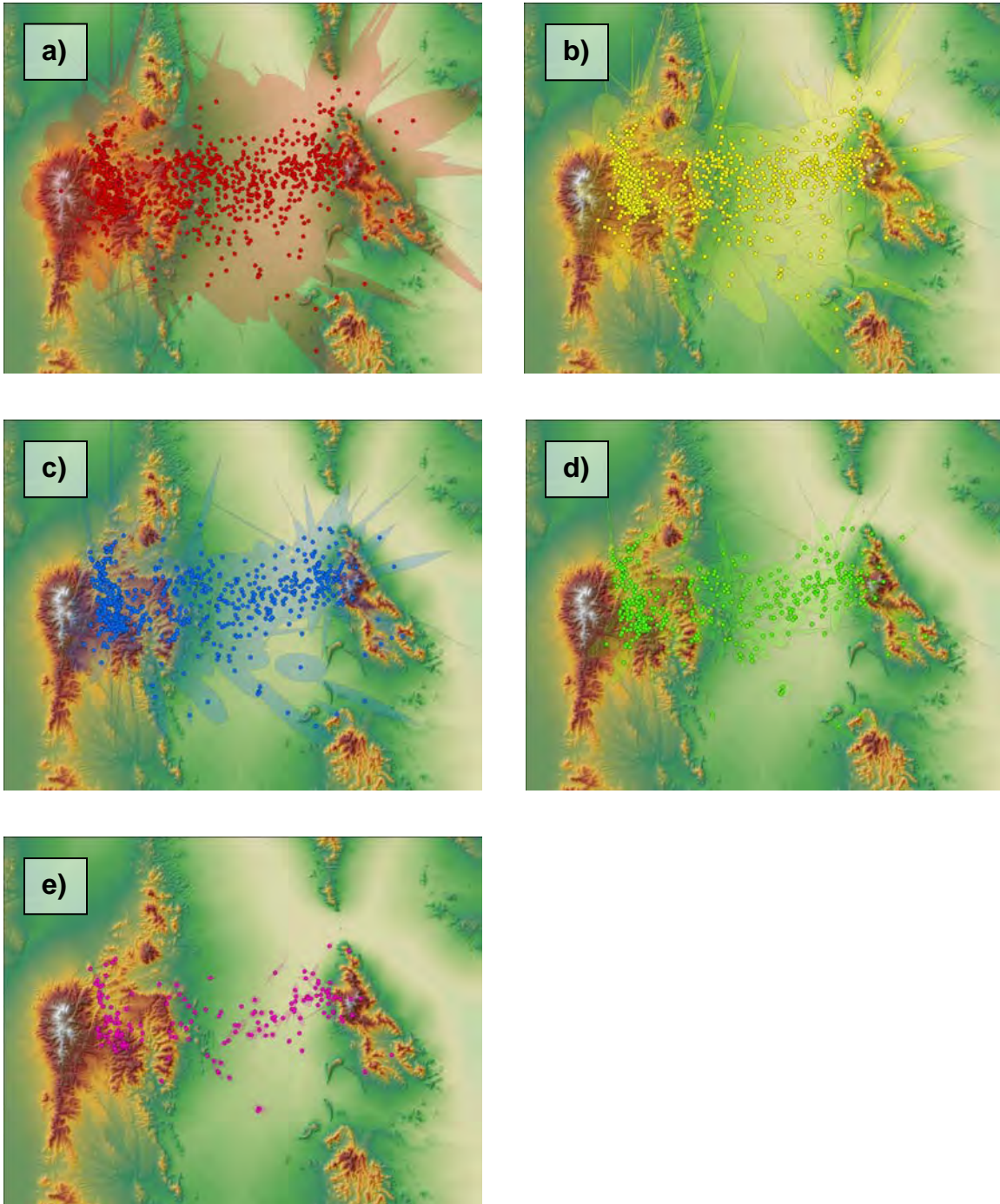


Figure 5. Number of locations estimated from radio telemetry data by hour after sunset. Solid bars represent location estimates for *L. curasoae* and striped bars represent those of *L. nivalis*.

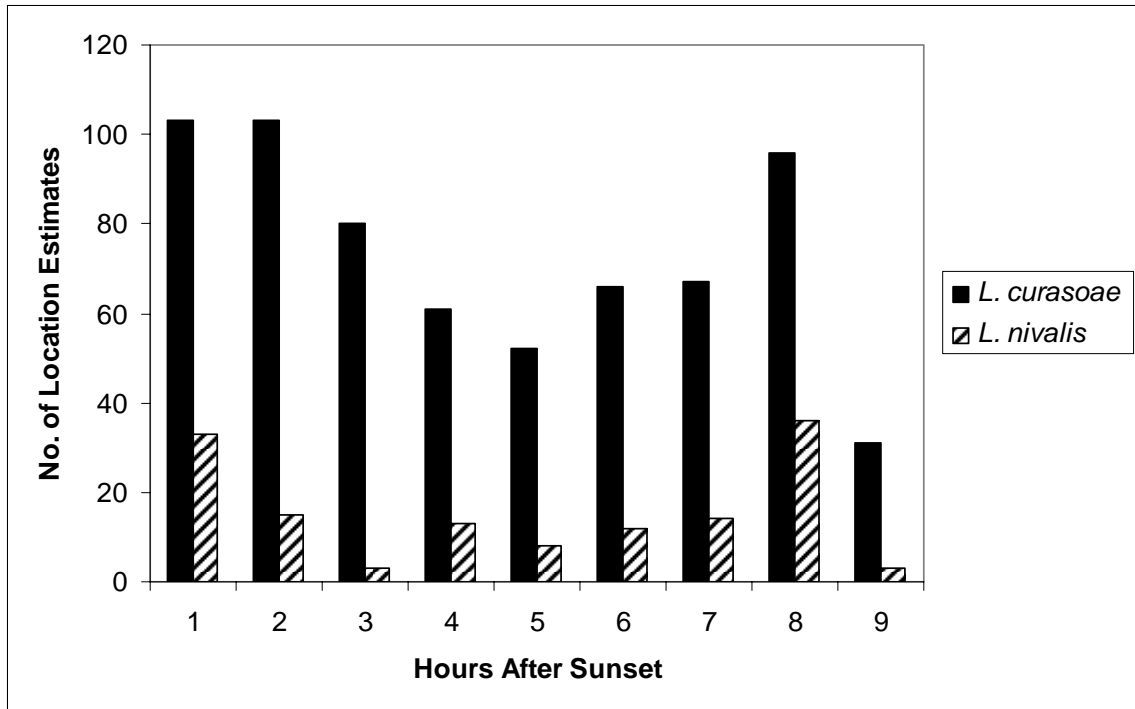


Figure 6. Distribution of location estimates of *Leptonycteris* with error of ≤ 100 km², showing differences in overall distribution between species. Red circles represent *Leptonycteris curasoae*, green circles represent *L. nivalis*.

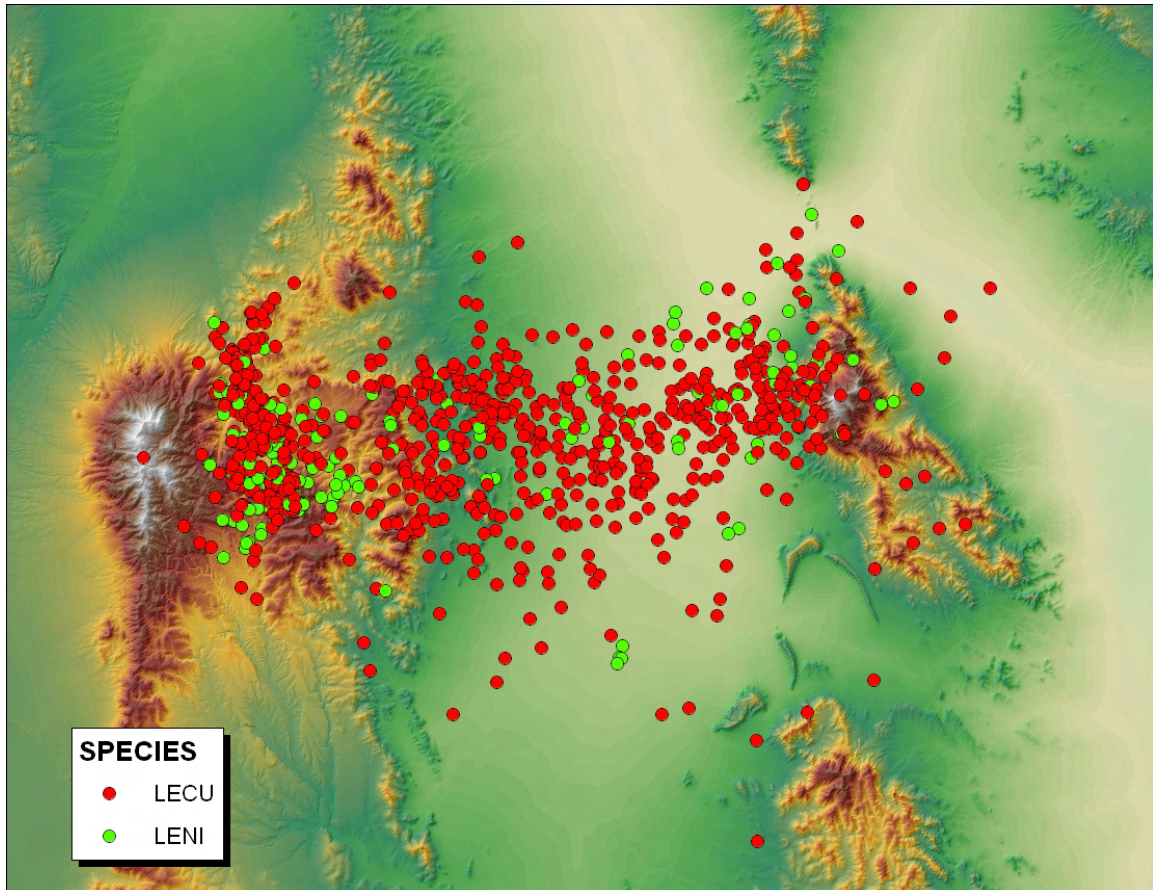


Figure 7. Distribution of location estimates of *Leptonycteris* with error of ≤ 100 km², showing differences in overall distribution between sexes (both species combined). Pink circles represent females and blue circles represent males.

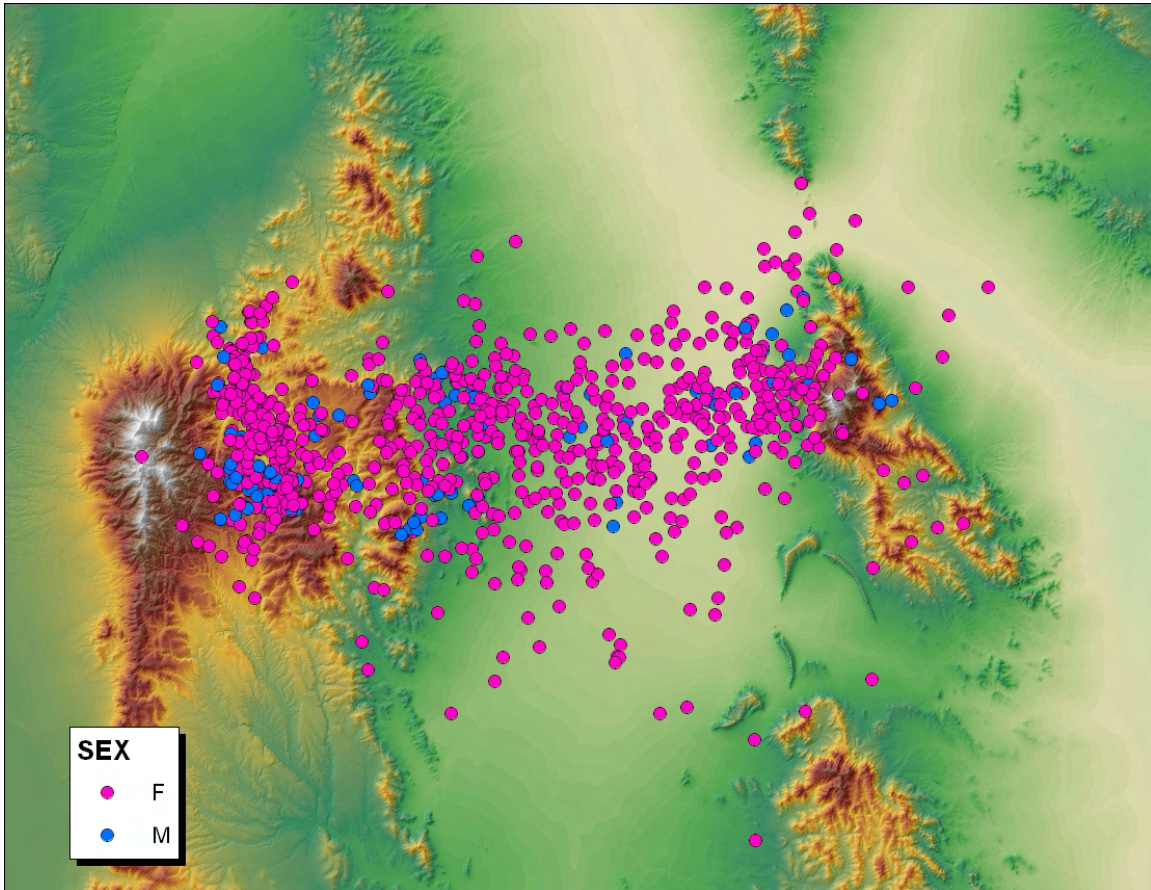


Figure 8. Distribution of location estimates of *Leptonycteris* with error of ≤ 100 km², showing differences in overall distribution between age groups (both species combined). Dark gray circles represent adults, light gray circles represent young-of-year, and white circles represent bats of unknown age.

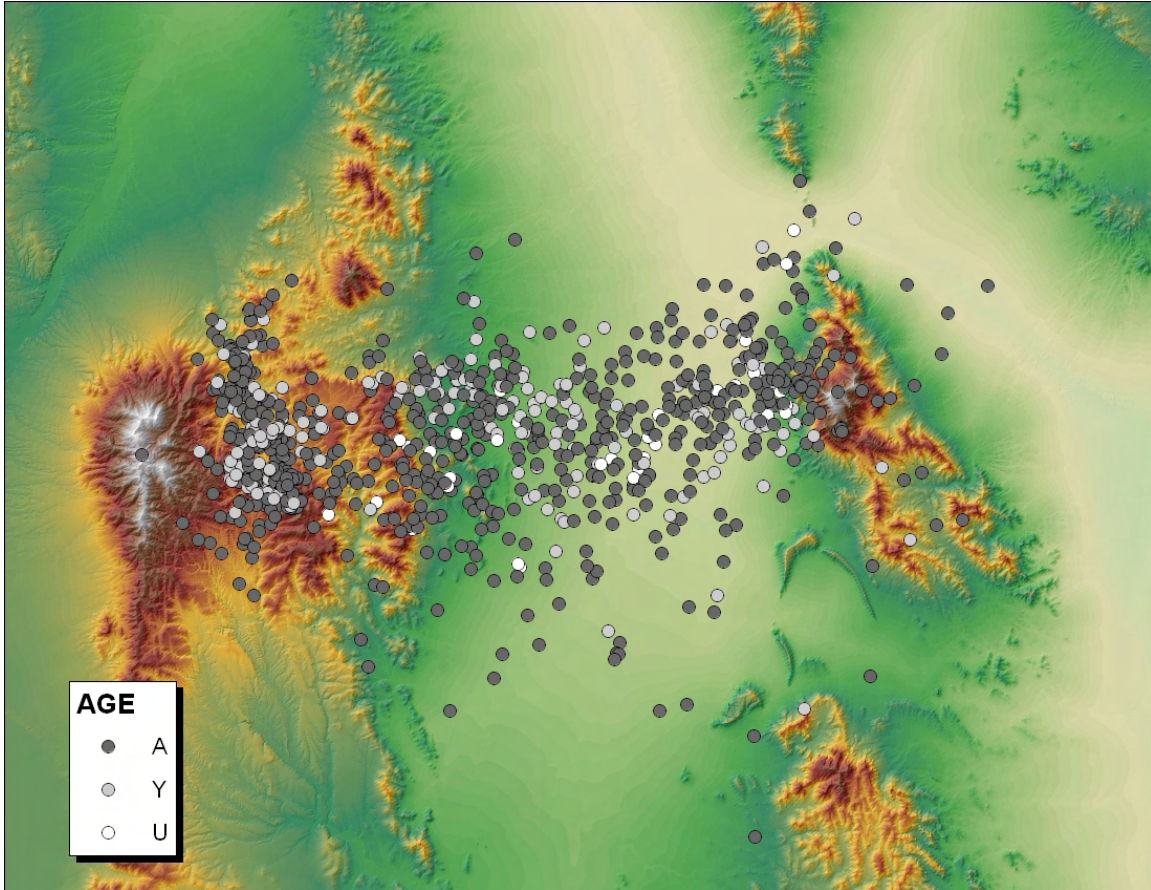


Figure 9. Distribution of location estimates of *Leptonycteris* with error of ≤ 100 km², showing differences in overall distribution between reproductive groups (both species combined). Yellow circles represent lactating females, purple circles represent postlactating females, and blue circles represent males and females that showed no visible signs of reproduction.

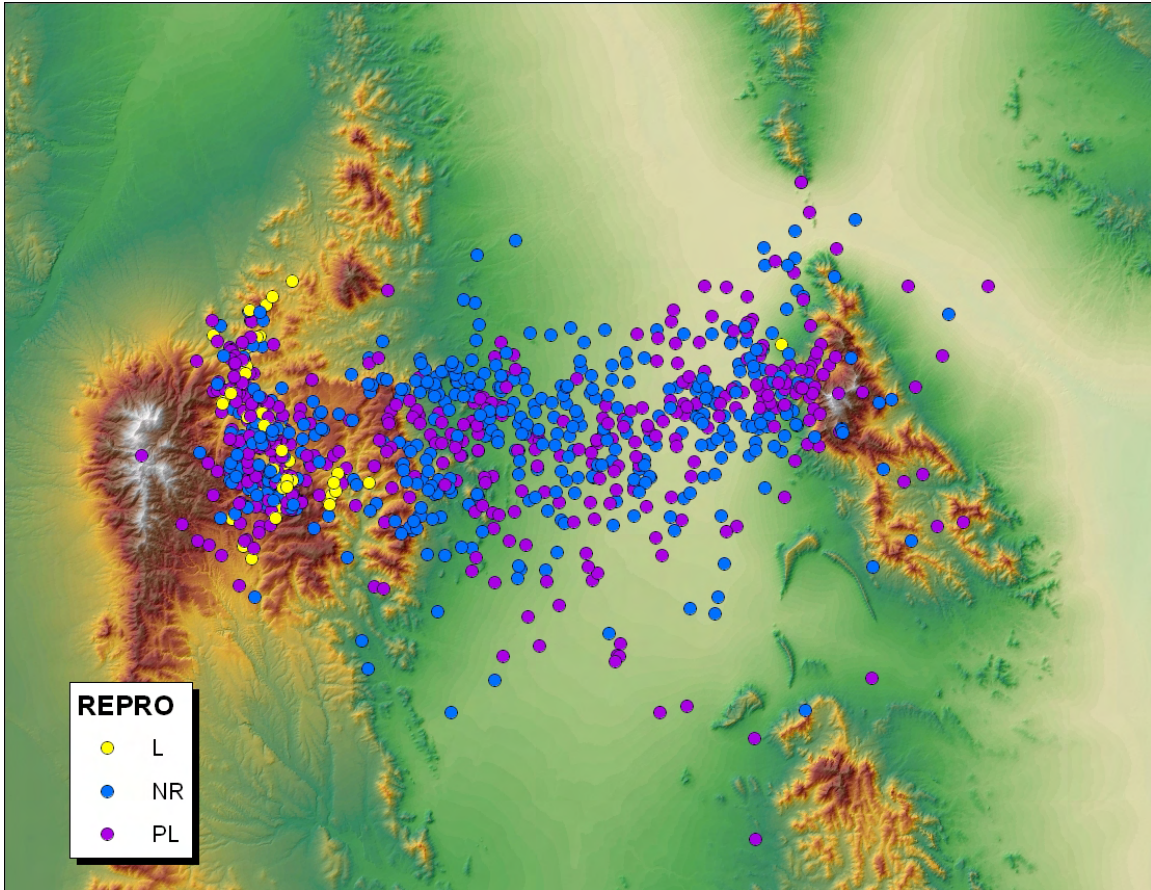


Figure 10. Distribution of location estimates of *Leptonycteris* with error of ≤ 100 km², showing differences in overall distribution between the two years of intensive radiotracking (2004 and 2005). Black circles represent location estimates from telemetry conducted during 2004 and white circles show locations made from the 2005 tracking data.

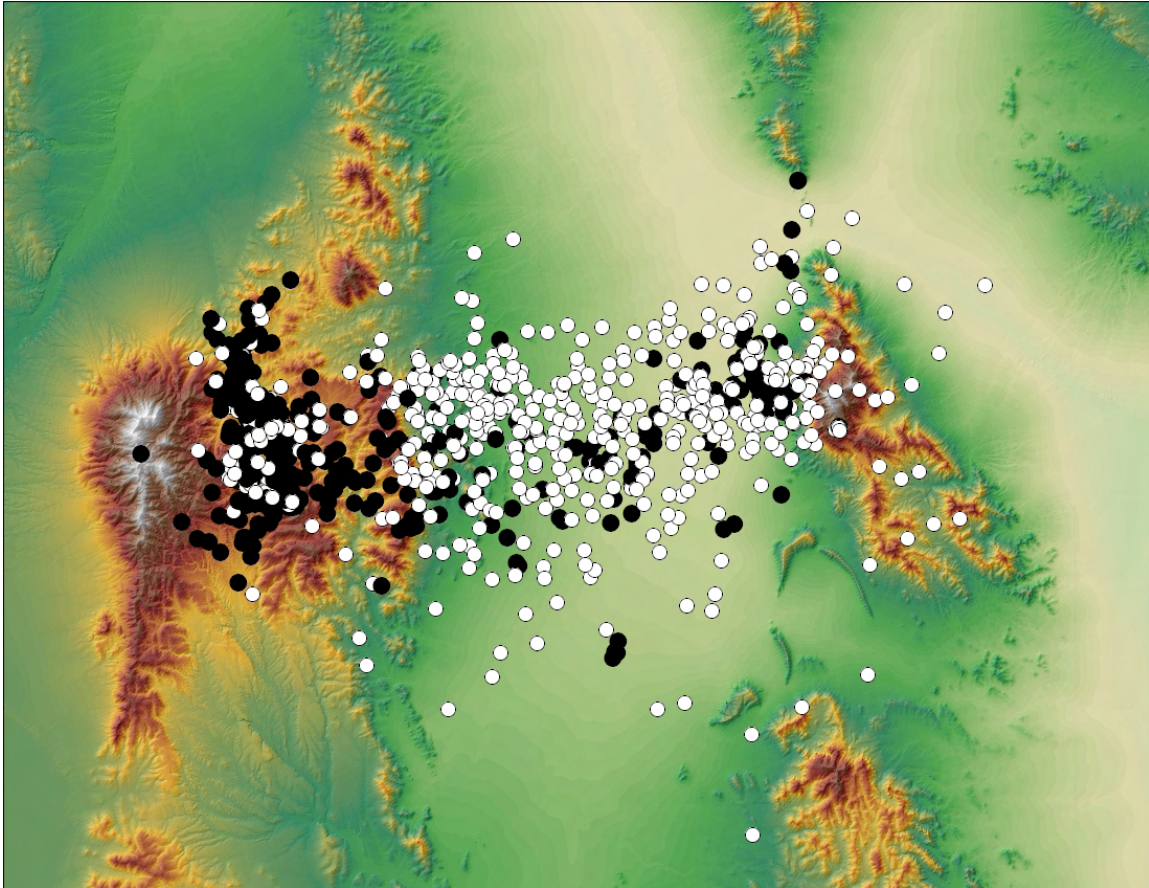


Figure 11. Extent of movement of individual bats ($n = 33$), by species, throughout general regions of study area. Solid bars represent *L. curasoae* and striped bars represent *L. nivalis*. The regions of the study area were the Animas Mountains, Playas Valley, Big Hatchet Mountains, and combinations thereof. See Fig. 1 for layout of study area. Tabular data used to construct this figure are included in Table 1.

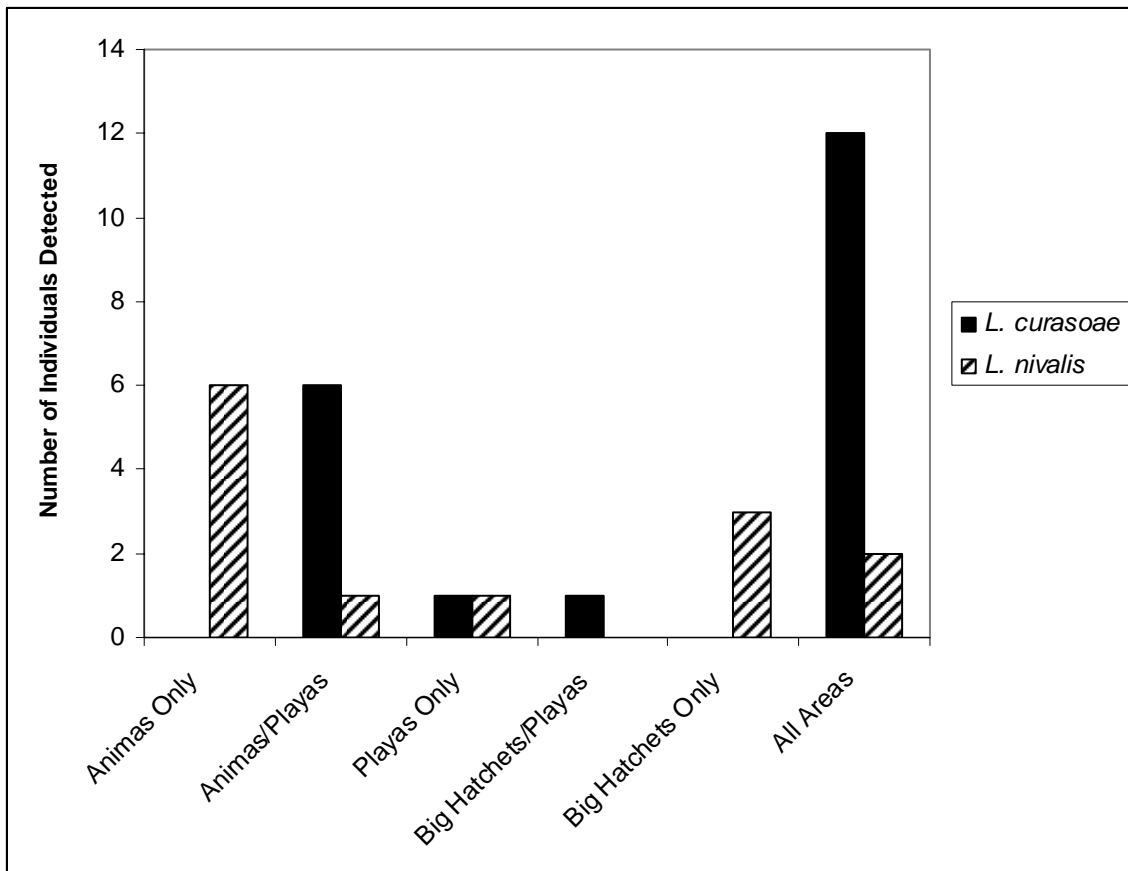


Figure 12. Relative density of location estimates for all *Leptonycteris* determined by radio telemetry during the summers of 2004 and 2005. Shades of white and light blue represent relatively low densities of locations and darker shades of blue represent areas where locations were more concentrated.

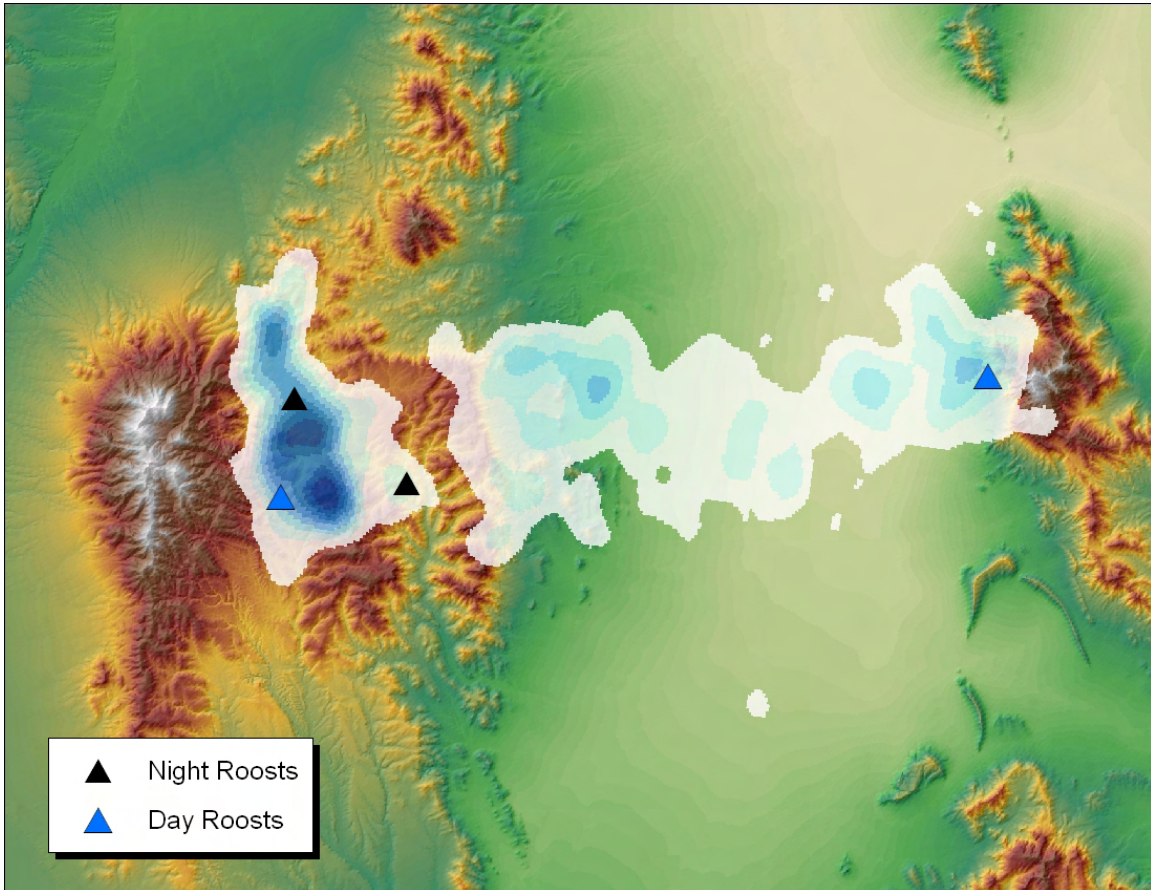


Figure 13. Number of bat locations, by hour after sunset, in three zones of the study area. Zones are illustrated in Figure 2 and encompass the general areas of: Zone 1 – Animas Mountains; Zone 2 – Playas Valley; and Zone 3 – Big Hatchet Mountains.

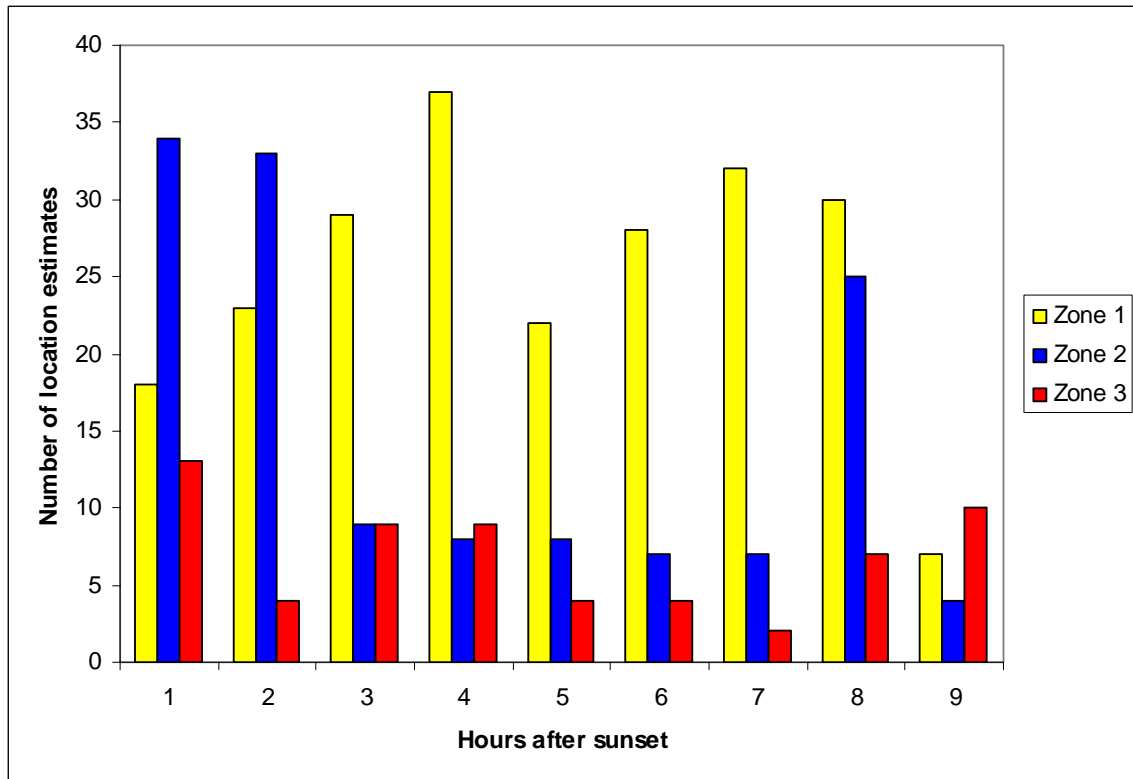


Figure 15. “Main” entrance of major day roost of *Leptonycteris* discovered during July of 2005 in the Big Hatchet Mountains. For scale, note person in right center of photo.



Figure 16. “Crevice” entrance to major day roost of *Leptonycteris* discovered during July of 2005 in the Big Hatchet Mountains. Floor of crevice drops off vertically just past the point where the person is standing. Crevice depth estimated to be > 70 m (see text).



Figure 17. Counts of bats emerging at dusk from two major day roosts used by *Leptonycteris curasoae* and *L. nivalis* in the Animas (blue bars) and Big Hatchet (maroon bars) mountain ranges. Data are from individual counts (i.e., not pooled across years) carried out during the summers of 2003 through 2005 and are displayed by day of the month, irrespective of year.

