Urban Movement patterns of Lesser Long-nosed bats (*Leptonycteris curasoae*)**: Management Implications for the Habitat Conservation Plan within the City of Tucson and the Town of Marana.**

Submitted to:

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Introduction

The lesser long-nosed bat (*Leptonycteris curasoae*) is a federally listed endangered species in the U.S. (Shull 1988) and Mexico (SEDESOL 1994). This species feeds on the nectar, pollen and fruit from flowers of columnar cacti species such as the saguaro (*Carnegiea gigantea*) and organ pipe cactus (*Stenocereus thurberi*), and from paniculate agaves such as Palmer's agave (*Agave palmeri*) and Parry's agave (*A. parryi*) (Howell 1974, Fleming et al. 1993, Godinez-Alvarez 2000, Valiente-Banuet 2000, Ober and Steidl 2004). The northern U.S. distribution of *L. curasoae* occurs in Arizona and extends from the Picacho Mountains, southwest to the Agua Dulce Mountains and southeast to the Chiricahua Mountains (including Tucson Basin, Santa Catalina, Rincon, Huachuca and Santa Rita Mountains) Rojas-Martinez et al. (1999) studied 1,881 records of *L. curasoae* from North American mammal collections spanning 94 years and concluded that this species is evidently migratory only in the northern populations (near 30° N latitude) where there exists a concurrent seasonality of floral resources. In the Tucson urban area these floral resources are extended both by time of year and elevation within the surrounding sky islands.

Migratory *L. curasoae* begin arriving in south-central Arizona by April (especially Organ Pipe Cactus National Monument) when columnar cacti begin flowering, and form maternity roosts numbering in the several thousands of pregnant females (Arita 1991, Cockrum 1991, Fleming et al. 1993, Wilkinson and Fleming 1996, Cole and Wilson 2006, Morales-Garza et al. 2007). Females have been documented to use the same roosts repeatedly (Hayward and Cockrum 1971), however, inter-annual variation in colony sizes is also typical (Alvarez and Gonzalez 1970, Alvarez et al. 1999, Ceballos et al. 1997, Herrera 1997, Quiroz et al. 1986, Stoner et al. 2003, Tellez et al. 2000). During late summer and early fall many *L. curasoae* use roosts in southeast Arizona where their primary food source becomes nectar from flowering agaves (Fleming et al. 1993, Ober and Steidl 2004). Wilkinson and Fleming (1996) analyzed *L. curasoae* mitochondrial DNA and suggested this species uses two migratory routes consisting of a columnar cacti route in thorn scrub and tropical dry forest containing columnar cacti, along the west coast of Mexico and an agave route along the western foothills of the Sierra Madre Occidental. Morales-Garza et al. (2007) further refined migratory data with random amplified polymorphic DNA and determined that “very little gene flow” occurred with the most southern population sampled in south-central Mexico; however, northern *L. curasoae* populations “maintain a considerable level of gene flow” with a major roost located in Jalisco, Mexico. The populations located near Chamela, Jalisco and Los Mochis, Sinaloa are believed to be the latitudinal boundary between migratory and resident *L. curasoae*, where migrants and year-round residents intermix in November-December (Stoner et al. 2003).

The degree of urbanization that *L. curasoae* will tolerate is not well understood. The purpose of this project was to determine the movement patterns (e.g., flight corridors, location of foraging patches, locations of night and day roosts) in and around the City of Tucson and Town of Marana, concentrating on lands within the jurisdiction of their respective Habitat Conservation Plans. Movement information is needed by local urban planners to manage for the persistence of this endangered species.

Study Area

Evaluation of urban movements by a migratory species requires a broad approach in order to achieve desired results. Our project area was defined as those lands covered by the City of Tucson and the Town of Marana Habitat Conservation Plans. In order to understand the relationship between these lands and surrounding areas, we extended the focus area to incorporate this broader area. This area can be generalized as the greater Tucson Basin which lies in northeastern Pima County, Arizona (Figure 1). The Tucson Basin lies within the Santa Cruz River watershed and encompasses most regions south of the Santa Catalina Mountains, west of the Rincon Mountains and east of the Tucson Mountains. Correspondingly, a diverse spectrum of vegetation associations characterizes the landscape including the Arizona Upland Desertscrub and Lower Colorado River Desertscrub subdivisions (Brown 1994). The predominant vegetation includes: ironwood (*Olneya tesota*) in the northwest, foothill paloverde (*Parkinsonia microphyllum*) characterizing the Catalina foothills, blue paloverde (*Parkinsonia floridum*) and velvet mesquite (*Prosopis velutina*) in the washes and floodplains, and saguaro, whitethorn acacia (*Acacia constricta*), catclaw acacia (*Acacia greggii*) and many *Opuntia* species throughout the region. Desert washes extend from the mountain slopes into the valley floors and consist of ephemeral water, denser vegetation and naturally incised banks. The annual rainfall ranges from 11-13 inches (30-35 cm) and occurs in two distinct periods: a winter wet season from November to April and a summer monsoon season from July to September (Adams and Comrie 1997). Within 30 km of the city center, elevation varies from 670 m (2,198 ft) in the northwest, to 2,791 m (9,175 ft) on Mt. Lemmon in the Santa Catalina Mountains.

Northeastern Pima County has experienced explosive population growth over the past few decades; encompassing 63,758 acres (227 square miles) with estimates of 1,012,018 residences in July 2008. Expected growth projections for the Tucson region estimate a population of 1.2 million by the end of the next decade. The Tucson metropolitan area (including un-incorporated regions) has a total population of well over 800,000.

Methods

Trap Site Selection

L. curasoae trap sites were selected through evaluation of detections reported by volunteer resident monitors or incidental reports by residents in target areas (Figure 1). When a resident monitor reported bat visitation at their hummingbird feeders, we arranged a site visit to confirm species identification and/or initiate a trapping effort. The availability of trapping locations and frequency depended on the number of program participants. We evaluated all bat reports and only rejected detections within the study area when the reported area was within two kilometers to a previous trap site.

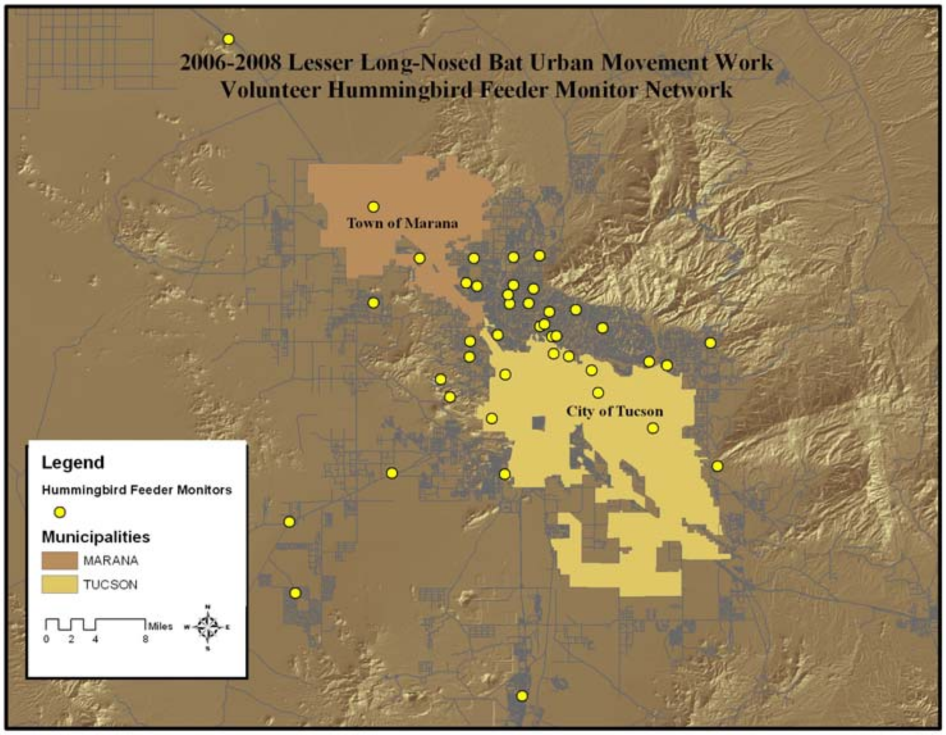

Figure 1. Study area illustrating the volunteer citizen scientist hummingbird monitoring network between 2006 and 2008.

Radio-Marking Techniques

L. curasoae were trapped from August – October at trap sites utilizing one mist net erected in front of hummingbird feeders and oriented to take advantage of flyway directions. At sites where multiple feeders were available, we erected our net where visitations were reported to be most frequent or where we directly observed bats during our monitoring session. Residents were instructed to leave the lighting conditions at the same level of previous detections. We used black nylon mist nets with four shelves (Avinet) of the following specifications: mesh size – 38 mm, height – 2.6 m, length – 12 m. Nets were left in place until the targeted species was captured and individuals were identified as adults of sufficient weight (i.e., > 23 g minimum). Only one individual was radio-marked during each trapping session. We mounted radio transmitters (Holohil models LB-2N and BD-2) weighing approximately 0.42 g on the back of each bat using medical skin glue (Skin Bond™). This transmitter weight easily falls within the accepted < 3.5% of body mass required for transmitter placement. Transmitter battery life was reported as one to two weeks and glue bonding was expected to last approximately 10 days after which the transmitter was assumed to fall off.

Radio-Tracking

We conducted ground radio-tracking using two vehicle-mounted 6-element radio telemetry antennas which were a modified variation of a null-peak antenna system described by Brinkman et. al. 2002. The yagi antennas were attached (~4-meters) above the vehicle in order to achieve a distance of two frequency wavelengths (Wavelength = ~1m @ 150.000MHz) above any interference created by the vehicle. Receivers (Communication Specialists, Inc., Model R-1000) were programmed and fine-tuned for best reception prior to release from trap site. Tracking crews were positioned to take advantage of high points and minimize obstacles during tracking periods, and attempted to maintain positions opposite each other during long-distance movements. We began tracking radio-marked individuals' immediately after release and attempted to maintain transmitter detections until the individual returned to its day roost. We recorded our position using both hand-held GPS units (Garmin models III and V) and compass bearings oriented along the antenna spine toward the peak signal(i.e., transmitter location). During foraging periods, triangulations were completed every 10 min after the hour and every 5 min during large movements between roosts and foraging areas. Tracking was conducted during 4 successive nights or until transmitters failed or individual bat movements could no longer be detected due to long-distance movements out of the study area. We used cell phones and hand-held radios to communicate positions and tracking strategies between crews during each tracking session.

Figure 2. Photo illustrating the telemetry setup adapted for tracking *L. curasoae* in an urban environment.

Data Analysis

Telemetry locations were determined using the maximum likelihood estimator (Lenth 1981) in the software environment LOAS 3.0.3 Ecological Solutions Software. Locations were mapped and travel distances were estimated using ESRI® Arc Map 9.3 and Hawth's Analysis Tools Version 3.27. Movement telemetry had an associated error of approximately one square kilometer while foraging locations error was estimated to be 500 sq. meters. Due to the distributional nature of lighting and large wash characteristics in the study area, we conducted a compositional analysis (Aebischer et al. 1993) to determine if selection was occurring for or against these two landscape features. Compositional analysis calculates the difference of log-ratios between use and availability of resource units. When no selection occurs, the mean values for the difference in log-ratios will be zero. Positive values indicate selection while negative values indicate avoidance.

Results

Trap Site Selection

The three year (2006-2008) duration of this study resulted in the trapping of *L. curasoae* at 19 sites within northeastern Pima County (Table 1). Our sampling was not uniformly distributed throughout the greater Tucson Basin. We trapped in areas where *L. curasoae* were identified by volunteer bat monitors and homeowners who reported presence of bats at feeders within the urban matrix of Tucson and Marana. The distribution of detections observed during this three year study was similar to an investigation into the urban distribution of *L. curasoae* utilizing feeders in the Tucson Basin (Wolf, 2006). Some Tucson sites were trapped multiple times in order to determine exactly where the bats were roosting or to resolve issues or questions posed during initial trapping sessions.

Table 1. 2006-2008 AGFD trapping and radio-tracking effort for *L. curasoae* in the vicinity of the City of Tucson and Town of Marana, Pima County, Arizona.

Year	Start Date	End Date	Trap Sites	Trap Sessions	*L.curasoae* Captures	*L.curasoae* Marked	Tracking Days
2006	8 Sept 06	9 Sept 06	2	2	2	2	2
2007	21 Aug 07	31 Oct 07	9	13	20	9	27
2008	2 Sept 08	23 Oct 08	8	9	15	7	26
Combined			**19**	**24**	**37**	**18**	**55**

Captures and Radio-Tracking

Twenty-four trapping sessions were conducted at these 19 sites which resulted in the capture of 37 *L. curasoae* (Table 1). During this study we captured four species of bats utilizing hummingbird feeders surrounding the Tucson Basin (Appendix 1). These bat species included our target species, *L. curasoae*, but in addition we captured the Mexican Long-tongued bat (*Choeronycteris mexicana*), Pallid bat (*Antrozous pallidus*) and Cave myotis (*Myotis velifer*). Of the 37 *L. curasoae* captured from 2006 - 2008, a higher percentage of adults (91%, n = 33) was trapped compared to juveniles (8%, n = 4) and more males (61%, n = 22) captured than females (38%, n = 14). Interestingly, percentages of captured male and female *L. curasoae* were similar among trap sites; Eastern Tucson captures (east of Sabino Canyon and Pantano wash) resulted in (males 59%; females 41%), central (North central Tucson and Catalina foothills) (males 67%; females 33%), and northwest Tucson (males 64%, females 36%). Yearly differences were observed with more males and fewer females being captured at feeder locations in 2007 (males: 80%, n = 16; females: 15%, n = 3) compared to 2008 (males: 26%, n = 4; females: 59%, n = 10) (Appendix 1).

Of the 39 *L. curasoae* captured, 18 were radio-marked and tracked for duration of 55 days (Table 1). During the course of the study, we documented four day roost locations in the Rincon, Empire mountains and Santa Catalina mountains and identified several flight corridors between roosts and forage areas within the Tucson urban area (Appendix 2, Figure 3).

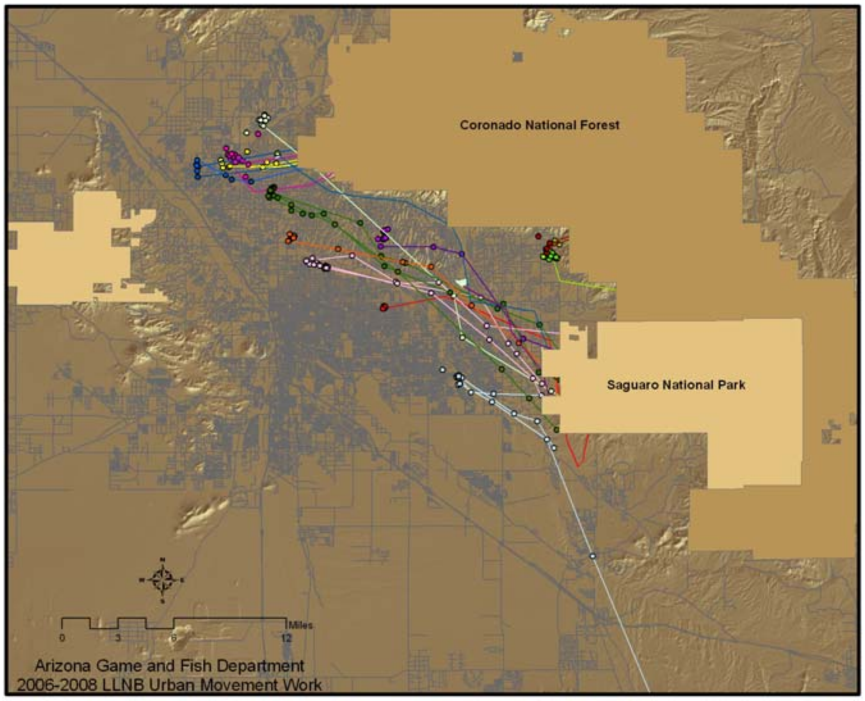

Figure 3. *L. curasoae* flight movements recorded from 2006-2008. Each color represents and individual bat followed over consecutive days.

Day Roosts

We identified four day roosts within the surrounding Tucson basin. These day roosts are identified as the Saguaro National Park roost, the Agua Caliente roost, the Catalina Roost and the Empire roost. Due to the sensitive nature of these data, exact locations of roosts have been omitted from this report. Land management agencies requiring more specific data should contact the Arizona Game and Fish Department's Heritage Data Management System.

High roost fidelity by tracked individuals was observed during this study. Seventy-seven percent of the bats marked with transmitters returned to the same roost over multiple nights. Two bats appeared to switch day roosts during this study but stayed within the study area and returned to the same foraging sites. It is unlikely that the four day roosts identified in this study constitute all of the roosts in northeastern Pima County. During the study, two bats were last tracked heading over Redington pass and did not return to the study area, possibly indicating another day roost on the east side of the Rincon Mountains or Galiuro Mountains. Efforts made to track these individuals throughout the San Pedro Valley were unsuccessful.

Flight Corridors and characteristics

We summarized each movement corridor or the route traveled from roost to foraging area according to time of departure and time of arrival between day roosts and forage areas (Appendix 3). Distances traveled during these movements were also summarized along projected telemetry paths and average travel rates were calculated (Appendix 3). In terms of movement trajectories to and from foraging areas and roosts, these were not straight line movements. The average distance traveled along movement corridors in 2007 was 17.9 miles (SE = 1.2, n = 16), ranging from 6.4 – 25.0 miles (10.2 – 40.2 km) between forage areas and day roosts. During the 2007 tracking season, we only recorded bats utilizing the Saguaro National Park roost and the Empire roost on the eastern side of the Tucson basin. During the 2008 tracking season, the average flight distance was 5.8 miles (SE = 0.94, n = 15), ranging from 1.5 – 14.3 miles (2.41 – 23.0 km). We identified two new day roosts in 2008: the Catalina roost and the Agua Caliente roost. These roosts were closer to the urban areas and resulted in shorter commute distances observed in 2008. During the 2007 – 2008 seasons, we sampled in similar areas within the study area, and it is uncertain whether *L. curasoae* occupied these new roosts during previous years. In 2007, radio-marked bats traveled faster to foraging areas (mean rate = 20.4 mph (32.8km/hr), SE = 2.4, n = 7) than on their return flights (mean travel rate = 16.0 mph, SE = 0.8, n = 9) to day roosts. Travel rates were similar between arrival (mean travel rate = 10.6 mph, SE = 1.9, n = 6) and return flights in 2008 (mean travel rate = 11.2 mph, SE = 1.5, n = 7). Interestingly, both arrival and return flight travel rates were higher in 2007 than in 2008.

Our initial hypothesis was that utilization of flight corridors with respect to desert wash features and light intensity is expected to be proportional to the composition of the study area. We defined the comparative study area as a minimum convex polygon which encompassed 95% of all telemetry locations through the duration of the project (2006- 2008). The composition of washes in the total study area was determined by buffering all large (10,000 cfs) washes by increments of 1,000 m from any given wash and extended it to the study area boundary. We utilized 1,000 m increments to determine broader thresholds of movements in relation to the larger study area. In a GIS environment, we intersected all telemetry points with this developed layer gave us the proportion of telemetry points that intersected buffered wash increments. Compositional analysis of distance to washes indicated direct selection for areas closer to washes ($X^2 = 74.232$, d.f.= 6, $p < 0.0001$). This shows that within the urban matrix, bats did not move through the environments at random nor did they move in direct straight lines, they moved through areas which were closer to the washes than expected by chance.

Use of the study area by *L. curasoae* based on light intensity was analyzed indirectly. We analyzed the proportion of area within various light intensity management areas in northeastern Pima County. Light emissions within these areas are managed by zones of maximum light intensity or maximum mean lumens per net acre (Table 2). Within the defined study area, we hypothesized that bat movements should be proportional to the represented light management areas. The composition of light management zones were represented in the study area by; E1a = 20.4%, E2 = 18.4%, E3 = 23.7%, and E3a = 37.4%. Compositional analysis of light intensity showed that the movements were not random with respect to light regime. Telemetry locations indicated direct selection toward areas managed for lower light intensity ($X^2 = 18.5148$, d.f.= 3, $p < 0.001$). Specifically, the resource selection matrix showed selection toward zone E1a and against management zones E2, E3, and E3a. "Lighting Area Ela" is defined as special areas around astronomical observatories and those areas within any national park, monument, or forest boundary. In these areas, the preservation of a naturally-dark environment is considered to be of paramount concern. This indirect analysis shows that bats were moving through areas managed for lower light intensity and avoiding areas of greater light intensity. A high quality night image of light emissions in northeastern Pima County did not exist for direct analysis but these findings followed anecdotal observations.

Table 2. Pima County lighting code management zones and lumen intensities.

Maximum Total Outdoor Light Output Requirements						
Lumen Caps: Mean Lumens per Net Acre						
	Lighting Area (Defined in Section 4.9)					
	E3	E3a	E2	E1c	E1b(5)	E1a
Commercial and Industrial - Option 1 (1)(2)(Mostly LPS)						
Total (FCO* LPS**, plus FCO non-LPS)	450,000	350,000	200,000	125,000	48,000	18,000
Limit on non-LPS FCO	45,000	35,000	18,000	6,000	3,000	3,000
Limit on unshielded component, LPS or Non-LPS lighting	12,000	9,000	6,000	3,000	3,000	0
Commercial and Industrial - Option 2 (1)(2)(FCO for all Lighting)						
All lighting must be FCO	300,000	150,000	65,000	25,000	25,000	12,500
Limit on unshielded component	0	0	0	0	0	0
Commercial and Industrial - Option 3 (1)(2)(FCO for most lighting)						
Total (FCO plus unshielded)	200,000	100,000	50,000	25,000	12,500	12,500
Limit on unshielded component	12,000	9,000	6,000	3,000	3,000	0
All Residential Zoning (3)(4)						
Total (FCO plus unshielded)	55,000	39,000	24,000	15,000	12,000	12,000
Limit on unshielded component	12,000	9,000	6,000	3,000	3,000	3,000

Forage Areas

Radio-marked bats exhibited high forage site fidelity during this study. Each evening 100 % of bats tracked for multiple days would return to the previous night's foraging area. Other than minor movements away from the defined core forage area, none of the bats we investigated moved to new areas. Due to this forage area fidelity, we were able to differentiate long distance movements from forage area movements. This allowed for the separation and further analysis of movement corridors from forage areas. We quantified bat use within the forage areas by the smallest area containing 95% of all forage area telemetry locations (Figures 4 and 5). Home ranges were calculated using the fixed-kernel method (Worton 1989). In 2007 forage areas ranged from 281 – 511 ha with a mean of 400 ha (SE = 34, n = 6). In 2008 forage areas ranged from 214 – 881 ha with a mean of 505 ha (SE = 92, n = 6). Hummingbird feeders were the primary source of forage during this study. Two genera of columnar cactus were encountered at multiple forage sites which were utilized by bats. These two genera were *Stenocereus* spp. and night blooming *Cereus* sp. columnar cactus both were in bloom during the study period.

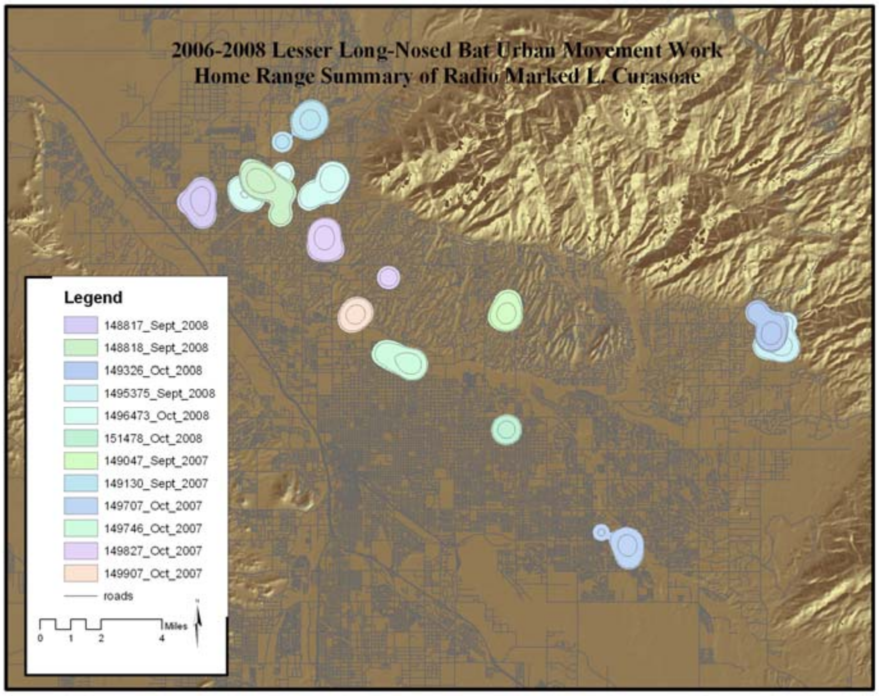

Figure 4. Fixed-kernel home range estimates at 95% for 2006-2008. Each color layer represents the summarized movements of an individual bat foraging area.

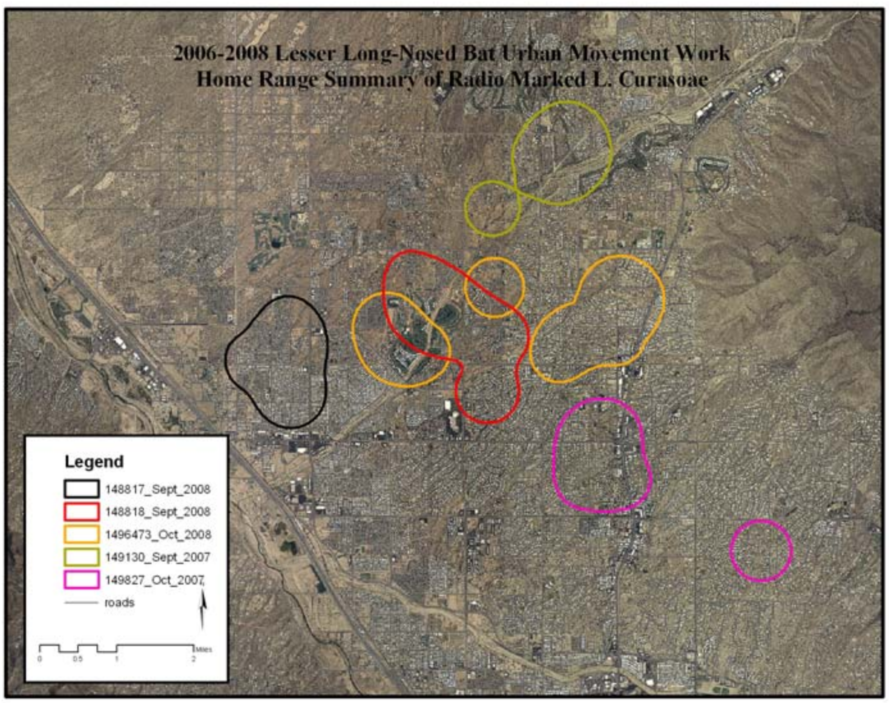

Figure 5. Detailed view of home range estimates within northeastern Pima County. Each color layer represents the summarized movements of an individual bat foraging area.

Night Roost Descriptions:
All bats foraged on hummingbird feeders consistently and returned to their established foraging areas shortly after sunset each night we monitored. Captured individuals also used a range of night roosts (e.g., vaulted roofs, trees and barns) where individuals probably rested briefly during foraging (Table 3). Narratives for each *L. curasoae* trap location are described below in further detail.

Jeremy Wash
One transmitter was affixed to an individual at this location on 8/21/07. This location was also the first in the Tucson region to report *L. curasoae* detections during the 2007 and 2008 season. This individual used a barn along Old Spanish Trail Road as a night roost after departing the foraging site where it was initially captured. After tracking this individual for a single night the transmitter either failed or the bat left the study area. This area is characterized as low urban density with one house per 1-5 acres.

Agave Drive
Two *L. curasoae* were affixed with transmitters, one on 9/11/2007 and one on 10/29/2007. The first individual was ultimately tracked heading east beyond Redington Pass and did not return to the study area after repeated efforts monitoring this frequency for another two weeks. A second bat was fitted with a transmitter at this capture location and returned to the Saguaro National Park roost. For three subsequent nights this individual was tracked moving between this roost and its forage area near River Road and Stone Ave. This bat utilized an abandoned house on a hill north of River Road at Stone Ave. On a single evening this bat was located at this abandoned house after it was not detected leaving the roost it entered the night before. We documented this bat foraging at a night blooming columnar cactus (*Cereus* sp.).

Calle Bosque
The first record for *L. curasoae* foraging at hummingbird feeders at the Sunrise Drive capture location occurred on 8/26/2006; identification of nectar-feeding bats as *L. curasoae* was accomplished with the aid of infrared night-vision videography equipment. *L. curasoae* visited the hummingbird feeders at this location until 10/4/2006 and were not observed again until 9/12/07. One individual was captured and affixed with a transmitter at 22:30 on 9/19/07 and was documented foraging and night-roosting further south along Calle Bosque. Similar to the Sunrise Drive trap-site, this location is in low-density development (approximately 1 house per acre with additional wash / natural open space components). The night roost consisted of a dark vaulted front entrance to a private residence and ultimately returned to the main day roost.

CDO
This bat was captured west of La Canada road along the Canada Del Oro wash. This bat selected a night roost within comparatively high-density housing (with minimal open space) in a dark and vaulted front entrance of a residence. Despite selecting a night roost in a high-density residential location, this region of town (Lambert and La Canada) does possess many acres of low-density development and numerous washes and natural open space. This bat foraged along the Canada Del Oro wash through a gradient of urban densities ranging from 1 house / (0.25 -1acre lots).

Wildcat Drive

During our reconnaissance visit we captured multiple females at this location. During the second trapping session one week later we only trapped males. The home owner contacted the AZGFD office regarding fecal matter accumulation on his vehicles within his carport. One individual was captured and affixed with a transmitter on 10/2/2007 at this carport near Golf Links and Pantano Roads. There were numerous hummingbird feeders throughout the neighborhood and this bat exhibited a considerable amount of local movement. This individual switched roosts from the Saguaro National Park roost to the Empire roost and then back again during the 4 day monitoring session.

Allen Street

One individual was captured and fitted with a transmitter on 10/8/2007 at a residence reporting bat activity at their backyard hummingbird feeder. This location was near Country Club Drive north of Prince Road. Moderate levels of residential and business development characterize this location; however, open space is especially prominent along the Rillito River just north of this trap site. This *L. curasoae* was tracked along the south side of the Rillito River to the University of Arizona Agricultural center on Campbell and Roger roads, where it used a large tamarisk tree as a night roost before ultimately returning to the Saguaro National Park roost.

Giaconda Way

Two bats were fitted with transmitters at this location near Ina and Oracle Road. This is one of the few areas in 2007 where we captured female *L. curasoae* bats. After release this bat moved over to the neighbor's vaulted entrance way and promptly discarded the transmitter. The transmitter was relocated on the ground and successfully attached to another *L. curasoae* individual on 10/17/2007 the subsequent night. This bat remained in the trap-site neighborhood visiting several hummingbird feeders and shifted occasionally across Ina Road to the Tohono Chul Park area until it made a final departure and returned to the Saguaro National Park roost. We documented this bat foraging on a night blooming columnar cactus (*Cereus* sp.).

Agua Caliente

Two bats were affixed with transmitters at this location near Agua Caliente canyon during the 2008 season. The first captured individual foraged within the neighborhood and eventually flew up Agua Caliente Canyon presumably returning to a day roost. Eventually this bat left the study area traveling over Redington Pass prior to sunrise, suggesting a roost near Redington pass. Further efforts to relocate this individual were unsuccessful. The second bat trapped at this locality remained in the trap-site neighborhood visiting several hummingbird feeders at the trap house and shifted to other houses in the same neighborhood. This captured individual was also tracked up Agua Caliente canyon where further triangulation documented a new roost best described as a tectonic cave, presumably where the first captured individual roosted during the day. Both of these bats utilized night roosts under porches of vacant houses near the trap site.

Azalea

This bat was captured on Azalea Drive near Thornydale and Cortaro Farms Road and was the closest to the town of Marana. This individual foraged in the urban matrix north of Ina Road between Thornydale Road and Camino de Oeste. Between foraging sessions, this bat utilized dark carports and porches in this neighborhood as night roosts. Ultimately this bat was followed back to a new roost identified as the Catalina roost. This was the first documentation of *L. curasoae* utilizing this roost.

Placita Cuneca

This individual was captured at a small feeder on Placita Cuneca near Magee and La Cholla. This individual foraged primarily and night-roosted at Omni Tucson National Country Club. The night roosts utilized by this bat were dark porches and carports along La Cholla Boulevard. This bat was tracked over multiple nights utilizing the same night roosts and ultimately returned to the same day roost. This bat utilized the recently identified large day roost in the Catalina Mountains.

Citrus

This individual was captured at a feeder near East Pima St. and Columbus Avenue. This forage area would be characterized as urban core. This individual foraged within the neighborhood and utilized the eves of a small church as a night roost. This bat was the only bat during the 2008 season that returned to the Saguaro National Park roost. This bat was tracked for a single evening session. This bat returned to the roost by traveling NE of the trap site north of Grant road and along the Pantano wash towards the SNP roost. The next night the bat emerged and traveled in a south-west trajectory through the southlands (i.e., the area directly east of Interstate 19 and south of Interstate 10) where the signal was lost.

Hardy

This individual was captured near Oracle and Hardy Road, and foraged within the Rancho Feliz neighborhood containing the trap site and Omni Tucson National Country Club. This bat ultimately used the large day roost located within the Catalina Mountains.

Table 3. Night roost descriptions for all *L. curasoae* individuals affixed with a transmitter during the 2007 and 2008 telemetry seasons.

Capture Location	Night Roost Description
Jeremy Wash	Barn north of Old Spanish Trail, dark residential porch.
Agave Drive	Abandoned house at Stone Ave. & River Road, residential porch ramada at community pool. All with dark and quiet conditions.
Calle Bosque	Dark covered patio at trap-site; dark vaulted entrance at residence on Calle Bosque in low-density (development) neighborhood.
CDO	Dark vaulted entrance at residence in high-density (development) neighborhood off of La Canada.
Golf Links	Dark carport at trap-site in moderate-density residential neighborhood.
Allen Street	Large tree in row of Tamarisk at U of A Agricultural Center; dark porch in trailer park; shed in dark and low-density residential neighborhood.
Giaconda Way	Vaulted entrance to residence, moderate-density residential neighborhood as trap-site residence.
Agua Caliente	Large vacant house adjacent to trap house, and small barn in residential area.

Azalea	Dark carport and porch at various locations.
Placita Cuneca	Beneath covered patio of townhomes along Omni Tucson National golf course fairway.
Citrus	Beneath eves of church within trap neighborhood.
Hardy	Beneath covered patio of houses on Omni Tucson National golf course fairway and large utility shed near trap site.

Discussion

Contrary to what has been observed in other telemetry studies with *L. curasoae*, we did not observe straight line flights for all individuals between day roosts and foraging areas (Ober 2005, Horner et al. 1998). Simply stated as an issue of energy expended, the least cost path between two points is defined as a straight line. Through our telemetry analyses, we determined that this urban population did not follow this simple rule which suggests that the radio marked bats were selecting for or against features in the landscape. In the urban matrix of northeastern Pima County, we focused on landscape features that were anecdotally identified during the progression of this study which suggested selection or preference.

Our data and the results of the hummingbird feeder monitoring program developed by the Town of Marana and the USFWS indicate that *L. curasoae* use the Tucson Basin heavily between September (potentially as early as August in some regions) and late October. Tagged *L. curasoae* utilized riparian corridors delineated by large 10,000 cfs washes. *L. curasoae* were also documented in areas containing higher density development than expected, however, open space was a large component of areas utilized in most cases. In addition, compositional analysis of light intensity showed direct selection toward areas managed for lower light intensity, specifically toward zone E1a. These results suggest that proposed development should avoid large washes, maintain open space in higher density development, and curtail light pollution in identified flight corridors and foraging areas. Confirmed night roosts included barns, trees (large native and non-native species) and buildings; including an apparent preference for vaulted entrances common in contemporary architectural designs.

All bats made relatively long-distance movements consisting of 1.5 – 25 mile (2.4 – 40 km) one way movements during each tracking night; however, *L. curasoae* have been documented making substantially longer movements to forage. Horner et al. (1998) reported that *L. curasoae* commute a total of approximately 100 km each night including a two-way 30 km flight from a day roost (Isla Tiburon) to the mainland near Bahia Kino, Mexico. During migration, some individuals from the Chamela sea cave roost in Jalisco, Mexico migrate to the southwestern U.S. maternity roosts, *L. curasoae* would be capable of covering great distances (at least 1,600 km) during an unknown time period. Stoner et al. (2003) conducted roost counts at the Jalisco roost and determined that colony numbers peaked in November-December and dropped to 5% of maximum size by June-July and to less than 1% of the maximum in August when population increases occur in southern Arizona. Another roost monitoring study in Guaymas, Mexico revealed that *L. curasoae* used the roost seasonally between March and August (Penalba et al. 2006). The relationship between roosts in western Mexico is poorly understood due to the difficulty in studying this species and the multiple theories of roost usage and migration patterns that persist. However, it is interesting to note that Stoner et al. (2003) documented large increases in the roost in Jalisco, Mexico during September (to 60% of the peak population), the same month that *L. curasoae* have recently been observed in abundance at hummingbird feeders in Tucson. Thus, it seems likely that *L. curasoae* maintain a dynamic migratory pattern where populations coexist at southern roosts for a portion of the year and radiate north in the spring-fall to form roost colonies in the spring-early summer (in roosts near blooming columnar cacti) and transient roosts in the late summer-fall (near agave corridors).

Some of the hummingbird feeder watch participants claimed to have had *L. curasoae* visiting hummingbird feeders outside of the heavy use time between August and October. These reports suggest some occupation of the Tucson basin by *L. curasoae* year-round, however, these observations may have been of the Mexican long-tongued bat. *L. curasoae* were also incidentally observed in the Santa Catalina Mountains at hummingbird feeders near Summerhaven above 8,000 ft elevation in October (Shawn Lowery, per. Observ.). This contradicts previous reports that *L. curasoae* may have a minimum temperature threshold of 10°C (50°F)(Carpenter and Graham 1967, Cole and Wilson 2006) and indicates that this species is more tolerant of colder environments than previously thought. If *L. curasoae* are more resilient to colder temperatures than previously believed, apparent hummingbird feeder watcher observations of these bats outside of the migratory period may be credible. In addition, suitable roost structures within northeastern Pima County might have the internal conditions which mitigate against these cold temperature thresholds.

Management Recommendations

The principle reason behind the perceived historic decline of this endangered bat has been attributed to the disturbance of caves and mines throughout Arizona and Mexico where *L. curasoae* congregate in maternity colonies. The Lesser Long-nosed Bat Recovery Plan identified three habitat components necessary for the recovery of this species including: suitable night and day roosts and an abundance of forage plants (USFWS 1994). Correspondingly, it is crucial that wildlife managers be able to identify important night and day roosts, and adequate concentrations of food resources throughout the range of this species. There are two publicly known maternity colonies in Arizona that are located on federal lands and one on the Tohono O'odham Nation which correspondingly receive protection and monitoring; roosts in Mexico receive various levels of protection (USFWS 2006).

A symmetrically mutual relationship may not exist between *L. curasoae* and its food resources, particularly in the Sonoran Desert, where *L. curasoae* depend upon columnar cacti more than the columnar cactus rely on the bats for survival. Fleming et al. (2001) concluded that *L. curasoae* is a sporadic and unreliable (non-dominate) pollinator of columnar cacti in the Sonoran Desert as supported by data on low *L. curasoae* population densities in the context of high annual variation in fruit set. This is probably true when considered in the context of the complete range of cactus species such as the saguaro. However, *L. curasoae* clearly are important local pollinators as this species has been estimated making several foraging visits in Saguaro and Agave stands each night over a larger area (up to 100-250 ha) which is apparently necessary to maintain energy balance and potentially transferring pollen great distances (Horner et al. 1998). In arid tropical scrub regions like the Tehuacan Valley in southeastern Mexico, where nectar-feeding bats including *L. curasoae* are the exclusive pollinators of many columnar cacti species, densities of these bats are also reportedly low (Rojas-Martinez et al. 1999, Valiente-Banuet et al. 1996), and much of the population are permanent residents (Galindo et al. 2004). However, the number of flowers is much lower (one or two) per cactus per night in the Tehuacan Valley compared to the greater flower numbers (possibly dozens per individual) of saguaro and cardon cacti in the Sonoran Desert (Fleming et al. 2001). Although *L. curasoae* may be an unreliable pollinator of many Sonoran Desert columnar cacti and Agave species, these sources of pollen, nectar and fruit remain fundamental in maintaining the survival of this endangered species (Penalba et al. 2006). Correspondingly, it is imperative that these food sources be preserved to ensure the survival of *L. curasoae* despite this species recently heavy and seasonal use of hummingbird feeders (Stoner et al. 2003, Penalba et al. 2006).

These recommendations are based on the management of *L. curasoae* within an urban environment. Given the time of occupation (Aug – Nov) at this elevation, there are relatively few natural forage resources available. The primary food resource identified was that of the high carbohydrate diet of hummingbird feeder sugar water. It was noted that some individuals were also foraging on night blooming Cereus spp present in backyards with humming bird feeders. This creates an artificial food resource which these bats become dependant on in time of drought and low Agave production. The implications on delay of migration and potential physiological effects of this diet resource must be considered. With expected population growth and ultimate projections of an urban area extending from Sierra Vista, Arizona to Phoenix, Arizona, consideration must be taken of the implications of urban barriers to the overall movement patterns of this species. Due to these non-static pressures monitoring of this species as land use changes is essential.

Based on results from this study, we recommend the following habitat conservation guidelines and management actions to manage for the presence of *L. curasoae* in northeastern Pima County:

- Future development plans should avoid a distance of 1 km from large washes (10,000 cfs) when possible since *L. curasoae* were found to select these riparian areas as flight corridors. *L. curasoae* were selecting against areas greater than 2 km from large washes during commutes between day roosts and foraging areas.
- Plans for higher density development projects should include open space as a large component when possible. In this study, higher density development areas were utilized by *L. curasoae* as foraging areas and/or night roosts; however, we found that open space was a large component of these areas in most cases.
- Limit light pollution along identified flight corridors. Compositional analysis of light intensity showed that L. curasoae were directly selecting for areas managed for lower light intensity (i.e., zone E1a) and avoiding areas of greater light intensity (i.e., zones E2, E3, and E3a).
- Significant efforts should be made to protect and monitor known day roost locations.
- Additional telemetry projects should be implemented to identify new roost locations within the Tucson basin and other urban areas of southern Arizona.
- In accordance with USFWS (2005), research activities targeting the effects of urbanization on forage resources and behavioral patterns should be initiated within other areas of southern Arizona that are also experiencing rapid growth including Green Valley, Nogales, Sierra Vista, Benson, Vail, and Sonoita. This additional research may help further refine development thresholds and land uses that maintain or reduce foraging activity by *L. curasoae* in urban areas.

- Implications of artificial food resources (e.g., hummingbird feeders) on *L. curasoae* physiology and timing of migration (i.e., possibly delaying departure when natural resources are depleted) should also be investigated.
- Continue monitoring of L. curasoae occupation of the Tucson and Marana for new areas of foraging activity.

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Appendix 1: 2006-2008 AGFD bat captures in the vicinity of City of Tucson and Town of Marana HCP planning area boundaries, Pima County, Arizona.

Date	Time	Site	Area	Freq. I.D.	Species	Age	Sex	Weight (grams)
8-Sep-06	2021	Cloud	Cloud Rd. & Sabino	151.118	LLNB	Ad	F	29
9-Sep-06	????	Hardy	Hardy Rd. & Oracle	151.1	LLNB	Ad	M	30
21-Aug-07	2148	Jeremy	Saguaro NP East	None	MLTB	Ad	F	20.5
21-Aug-07	2148	Jeremy	Saguaro NP East	None	LLNB	Juv	M	29
21-Aug-07	2226	Jeremy	Saguaro NP East	None	LLNB	Juv	M	27
21-Aug-07	2240	Jeremy	Saguaro NP East	150.017	LLNB	Ad	M	28
11-Sep-07	2140	Agave	1st Ave. & River	149.017	LLNB	Ad	M	28
11-Sep-07	2140	Agave	1st Ave. & River	None	LLNB	Ad	M	26
18-Sep-07	2135	Diamond	Southeast of 3 Pts.	None	CAMY	Ad	M	10
18-Sep-07	2218	Diamond	Southeast of 3 Pts	None	MLTB	Ad	M	15.5
18-Sep-07	2219	Diamond	Southeast of 3 Pts.	None	PAB	Ad	M	24.5
18-Sep-07	2243	Diamond	Southeast of 3 Pts	None	PAB	Ad	F	25
19-Sep-07	2228	Scott	Craycroft & Sunrise	149.047	LLNB	Ad	M	23.5
19-Sep-07	2255	Scott	Craycroft & Sunrise	None	LLNB	Ad	M	21.5
25-Sep-07	2109	CDO	La Canada & CDO	None	LLNB	Ad	M	22.5
25-Sep-07	2120	CDO	La Canada & CDO	149.13	LLNB	Ad	M	24.5
27-Sep-07	2112	Wildcat	Golf Links & C. Seco	None	LLNB	Ad	F	29.5
27-Sep-07	2112	Wildcat	Golf Links & C. Seco	None	LLNB	Juv	F	23.5
3-Oct-07	2020	Wildcat	Golf Links & C. Seco	None	LLNB	Ad	M	25
3-Oct-07	2020	Wildcat	Golf Links & C. Seco	149.707	LLNB	Ad	M	27.5
3-Oct-07	2020	Wildcat	Golf Links & C. Seco	None	LLNB	Ad	M	23.5
3-Oct-07	2020	Wildcat	Golf Links & C. Seco	None	LLNB	Ad	M	26.5
3-Oct-07	2020	Wildcat	Golf Links & C. Seco	escaped	LLNB	-	-	-
8-Oct-07	2108	Prince	Prince & Country Club	149.746	LLNB	Ad	M	26
15-Oct-07	2145	Giaconda	Ina & Paseo Del Norte	149.827*	LLNB	Ad	F	30
17-Oct-07	2230	Giaconda	Ina & Paseo Del Norte	None	MLTB	Ad	M	22
17-Oct-07	2245	Giaconda	Ina & Paseo Del Norte	149.827	LLNB	Ad	M	27
29-Oct-07	1829*	Agave	1st Ave. & River	149.907	LLNB	Ad	M	26
2-Sep-08	2016	Jeremy	Saguaro NP East	None	LLNB	Ad	F	23.5
2-Sep-08	2020	Jeremy	Saguaro NP East	None	MLTB	Ad	F	18
2-Sep-08	2035	Jeremy	Saguaro NP East	None	MLTB	Ad	M	18
2-Sep-08	2039	Jeremy	Saguaro NP East	149.686	LLNB	Ad	M	29.5
15-Sep-08	2015	Agua Caliente	Agua Caliente	None	MLTB	Ad	F	17.5
15-Sep-08	2017	Agua Caliente	Agua Caliente	None	LLNB	Ad	F	20.5
15-Sep-08	2020	Agua Caliente	Agua Caliente	None	LLNB	Ad	F	21.5
15-Sep-08	2222	Agua Caliente	Agua Caliente	149.538	LLNB	Ad	F	25.5
22-Sep-08	2010	Azalea	Thornydale and Cortaro	None	LLNB	Ad	M	21.5
22-Sep-08	2015	Azalea	Thornydale and Cortaro	148.818	LLNB	Ad	M	23
29-Sep-08	2027	Placita Cuenca	Ina & La Cholla	None	LLNB	Ad	F	25
29-Sep-08	2030	Placita Cuenca	Ina & La Cholla	None	LLNB	Ad	M	28
6-Oct-08	2015	Citris	Grant and Swan	None	LLNB	Ad	F	24
6-Oct-08	2020	Citris	Grant and Swan	151.478	LLNB	Ad	F	30
14-Oct-08	2253	Hardy	Hardy Rd. & Norteno	149.647	LLNB	Ad	F	23
14-Oct-08	2323	Hardy	Hardy Rd. & Norteno	149.647	LLNB	Ad	F	20
20-Oct-08	2000	Agua caliente	Agua Caliente	149.326	LLNB	Ad	F	24

LLNB = Lesser long-nosed bat, MLTB = Mexican long-tongued bat, PAB = Pallid bat, CAMY = Cave myotis

Appendix 2: 2006-2008 AGFD trap summary and determined outcome.

Year	Trap Site	Location	Transmitter Placed	Date Tracked	Days Tracked	Roost Utilized	Determined Outcome
2006	Hardy	Hardy & Oracle	Yes	8-Sep-06	1	SNP Roost	Identified Flight Corridor
2006	Cloud	Cloud Rd & Sabino Canyon	Yes	9-Sep-06	1	SNP Roost	Identified Flight Corridor
2007	Jeremy Wash	SNP East	Yes	21-Aug-07	3	SNP Roost	Faulty Transmitter, Lost
2007	Agave	1st Ave & Rudasil	Yes	11-Sep-07	3	Agua Caliente	Identified Flight Corridor Determined New roost in area
2007	Diamond Bell Ranch	South of Three Points	NO	18-Sep-07	-	-	-
2007	Scott	Craycroft & Sunrise	Yes	19-Sep-07	4	SNP Roost	Identified Flight Corridor
2007	CDO	La Canada & CDO Wash	Yes	25-Sep-07	3	SNP Roost	Identified Flight Corridor
2007	Wildcat	Golf Links & Camino Seco	Yes	3-Oct-07	4	Empire Roost	Identified New Roost
2007	Prince	Prince & Country Club	Yes	8-Oct-07	4	SNP Roost	Identified Flight Corridor
2007	Giaconda	Ina & Paseo Del Norte	Yes	15-Oct-07	1	-	Large Female Removed Transmitter
2007	Giaconda	Ina & Paseo Del Norte	Yes	10/17/2007	3	SNP Roost	Identified Flight Corridor
2007	Agave	1st Ave & Rudasil	Yes	29-Oct-07	2	SNP Roost	Identified Flight Corridor
2008	Jeremy Wash	SNP East	Yes	2-Sep-08	2	SNP Roost	Lost
2008	Agua caliente	Agua Caliente	Yes	15-Sep-08	4	Agua Caliente	Determined New roost in area
2008	Azalea	Thornydale & Cortero	Yes	22-Sep-08	4	Catalina Roost	New roost identified
2008	Placita Cuneca	Ina & La Cholla	Yes	29-Sep-08	4	Catalina Roost	Flight Corridor Identified
2008	Citris	Grant & Swan	Yes	6-Oct-08	4	SNP Roost	Flight Corridor Identified
2008	Oro Valley CC	Oracle & First Ave	NO	14-Oct-08	-	-	-
2008	Hardy	Oracle & Hardy	Yes	14-Oct-08	4	Catalina Roost	Flight Corridor Identified
2008	Agua caliente	Agua Caliente	Yes	20-Oct-09	4	Agua Caliente	New roost identified

Appendix 3. *L. curasoae* flight times, durations, and distances and average rate of travel for 2007 -2008.

Date	I.D.	Emergence	Forage Area Arrival	Arrival Flight Time (min.)	Flight Distance (miles)	**Arrival Rate (mph)**	Depart Time	Day Roost Arrival	Return Flight Time (min.)	Flight Distance Miles	Return Rate (mph)
20-Sep-07	9.047	1948	2020	32	16.6	**31.13**	-	-	-	-	**Und**
21-Sep-07	9.047	1930	2011	41	16.5	**24.15**	-	-	-	-	**Und**
22-Sep-07	9.047	1906	1951	45	16.5	**22.00**	220	330	70	16.5	**14.14**
26-Sep-07	9.13	1918	2022	64	23.4	**21.94**	323	445	82	23	**16.83**
3-Oct-07	9.707	Capture Date	-	-	-	**Und**	414	445	31	7.2	**13.94**
4-Oct-07	9.707	1859	1922	23	6.4	**16.70**	0	150	110	24.9	**13.58**
8-Oct-07	9.746	Capture Date	-	-	-	**Und**	305	408	63	18.2	**17.33**
9-Oct-07	9.746	1847	2020	93	18.4	**11.87**	305	408	63	18.4	**17.52**
17-Oct-07	9.827	Capture Date	-	-	-	**Und**	300	412	72	21	**17.50**
18-Oct-07	9.827	1823	1942	79	19.9	**15.11**	305	409	64	21.2	**19.88**
29-Oct-07	9.907	Capture Date	-	-	-	**Und**	203	331	88	19.5	**13.30**
9/16/2008	149.538	1855	1902	7	1.6	**13.71**	-	-	-	-	**Und**
9/22/2008	148.8174	Capture Date	-	-	-	**Und**	350	440	50	7.6	**9.12**
9/23/2008	148.8174	1916	2030	74	7.6	**6.16**	353	450	57	7.6	**8.00**
9/30/2008	148.818	Capture Date	-	-	-	**Und**	400	500	60	6	**6.00**
10/1/2008	148.818	1908	2000	52	5.6	**6.46**	426	455	29	6.6	**13.66**
10/6/2008	151.478	Capture Date	-	-	-	**Und**	145	250	65	14.3	**13.20**
10/15/2008	149.647	1835	1910	35	5.8	**9.94**	340	405	25	4.3	**10.32**
10/16/2008	149.647	1825	1900	35	5.5	**9.43**	Und	-	-	-	**Und**
10/20/2008	149.326	Capture Date	-	-	-	**Und**	410	415	5	1.5	**18.00**
10/21/2008	149.326	1930	1935	5	1.5	**18.00**	420	Und	-	-	**Und**