



Preliminary Information on the Home Range and Movement Patterns of *Sturnira lilium* (Phyllostomidae) in a Naturally Fragmented Landscape in Bolivia

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ABSTRACT

Here, we used radiotelemetry to determine home range and movement patterns of the frugivorous bat *Sturnira lilium* in a naturally fragmented landscape in Beni, Bolivia. Four females were monitored for up to 7 d. Based on 575 radiotelemetry positions, kernel home ranges were between 36.5 and 90.7 ha. During each night, bats visited most of their home range, which included forest islands and continuous forest; however activity was concentrated in core-use areas representing 6–12 percent of the home ranges. There was moderate overlap in home range and core-use areas among the four females. The mean long axis across the kernel home ranges was 1324 m. The results reported here show that *S. lilium* is able to move freely among forest elements in the landscape while crossing a savanna matrix. Hence, *S. lilium* may contribute to maintain connectivity and ecological processes in a fragmented landscape.

Abstract in Spanish is available at <http://www.blackwell-synergy.com/loi/btp>.

Key words: chiroptera; fragmentation; frugivorous bat; Neotropical savanna; radio tracking.

HOME RANGE IS THE AREA WITHIN THE AVAILABLE HABITAT where an organism concentrates its daily activities (Feldhamer *et al.* 2004). The size of an animal's home range is determined by several factors, which include availability and dispersion of food (Ober *et al.* 2005), life-history traits (Kelt *et al.* 2001), and metabolic rate (Chaverri *et al.* 2007) among others. Additionally, habitat fragmentation can also play an important role in determining movement patterns and home range, as animals may need to use larger areas in fragmented habitats to acquire all necessary resources (*e.g.*, Albrecht *et al.* 2007, Chaverri *et al.* 2007). Additionally, fragmentation can have a particularly strong effect on movement patterns of forest-dwelling animals that may be reluctant to cross habitat-boundaries and/or non-forested matrices (Da Silva *et al.* 1996).

In a fragmented landscape, an open matrix can deter animal movement among forest elements because it differs dramatically from the forest habitat in physiognomy, availability of resources, and abiotic conditions. Limited movement to forest fragments can increase extinction probabilities of the remaining animal populations in the fragments (Bierregaard & Stouffer 1997, Sekercioglu *et al.* 2002). Moreover, when the animals moving across the landscape are important community interactors, such as seed dispersers, limited movement can further result in the disruption of ecological processes that are key for the persistence of these ecosystems (Webb & Peart 2001, Dalling *et al.* 2002).

Forest fragments, however, may not represent isolated islands for generalist species with high mobility (Lynam 1997). Unlike other frugivores, such as primates and understory birds (Bierregaard & Stouffer 1997, Sekercioglu *et al.* 2002), their high mobility allows many species of bats to persist in fragmented landscapes (Aguirre 2002, Montiel *et al.* 2006). It has been suggested that bats are more likely to cross nonforested matrices because their perception of the

differences between the forested habitat and the nonforested one is smaller (Malcom 1997) and evidence from recapture and telemetry data reveals that frugivorous bats are able to readily cross over non-forested matrices (Estrada *et al.* 1993a, b; Bernard & Fenton 2003; Albrecht *et al.* 2007).

Detailed movement patterns of bats in fragmented habitats within individual nights, however, have remained largely unexplored. It is still unclear for the vast majority of species for which there is telemetry data available, if movements across nonforested matrices are in fact common throughout the night or not. For example, Bernard and Fenton (2003) determined that individuals of *Carollia brevicauda* used up to seven forest fragments in a naturally fragmented landscape in Brazil during a 6–8 d period, but whether all those fragments were used on individual nights or during different nights have different implications. For example, when considering seed dispersal services by *C. brevicauda*, seeds are less likely to be moved among fragments if individual bats forage on a single fragment throughout the night; in contrast, foraging in several fragments will presumably promote interfragment seed exchange.

Sturnira lilium (Geoffroy 1810) is often among the most abundant bat species caught throughout the Neotropics (*e.g.*, Estrada *et al.* 1993a, Galindo-González *et al.* 2000, Galindo-González & Sosa 2003). It is an obligate frugivore that commonly feeds on pioneer species such as *Solanum* and *Piper* (Ludica & Bonaccorso 1997, Giannini 1999, Olea-Wagner *et al.* 2007) and it is considered a legitimate seed disperser (Fleming & Sosa 1994). *Sturnira lilium* roosts in tree cavities, vine tangles and the bases of palm fronds (Fenton *et al.* 2000, Evelyn 2003), and appears not to be affected by disturbance (Fenton *et al.* 2000, Galindo-González *et al.* 2000, Bernard & Fenton 2003, Galindo-González 2004). Consequently, *S. lilium* displays a combination of features that make it an ideal species in which to examine movement patterns in fragmented landscapes.

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In this study, we used radiotelemetry to assess movement patterns and home range of four *S. lilium* individuals in a naturally fragmented landscape (Langstroth 1996). Our goal was to determine: (1) which habitats were encompassed in the home range; and (2) how often did the individuals carry out interhabitat or interfragment movements across the savanna. We hypothesized that *S. lilium* individuals would move freely across the elements in the landscape and regularly cross the savanna to make either interhabitat movements between the continuous forest and the forest fragments, or movements among the fragments.

METHODS

STUDY AREA.—This study was conducted during the month of July 2001 (dry season) in the savannas of Beni Biological Station-Biosphere Reserve (BBS-BR) located in Beni, Bolivia ($14^{\circ}30'–14^{\circ}50' S$, $66^{\circ}40'–65^{\circ}50' W$; 200 m asl). The landscape in the study area consists of a natural savanna matrix with forest fragments (hereafter, 'forest islands') of various sizes (0.5–20 ha). On its northern border, a large block of lowland tropical forest borders the savanna. At BBS-BR, the savanna is divided into two major sections: one subject to low-density cattle-grazing, and one where cattle are excluded (section closest to the forest). This study was conducted in the latter section. Additionally, the landscape is dot-

ted in several degrees with isolated trees and vegetation patches that are considerably smaller than forest islands ($< 100 m^2$) and that can provide both food (*e.g.*, *Piper*, *Solanum*), and roosting sites for bats.

RADIOTELEMETRY.—We located an *S. lilium* roost in a tree (Moraceae) in a 1-ha forest island, which was located *ca* 700 m from the continuous forest line (Fig. 1). The entrance to the roost was *ca* 3 m from the ground, so we used mist nets to capture four nonreproductive adult *S. lilium* females (023, 063, 043, and 082) as they were leaving the roost between 10 and 17 July 2001. Weight, forearm and body length were recorded, and each bat was fitted with a 1.13 g radio transmitter (Model A1020, Advanced Telemetry Systems, Inc., Isanti, Minnesota, U.S.A.), with an approximate battery life of 10–15 d and whose signal could be received from up to 800 m. Transmitters were attached to bats by trimming mid-dorsal hair between the scapulae and applying SkinBond[®] surgical adhesive to the underside of the transmitter. Complete transmitter units weighed < 5 percent of the recommended body mass maximum (Aldridge & Brigham 1988). Radio-tagged bats were released the same night at the site of capture. Radiotelemetry data were not recorded on the night of release.

Bats were monitored for up to seven nights each (the number of nights determined by battery life) with two folding three-element Yagi antennas and two Fieldmaster 16 tracking receivers (Advanced

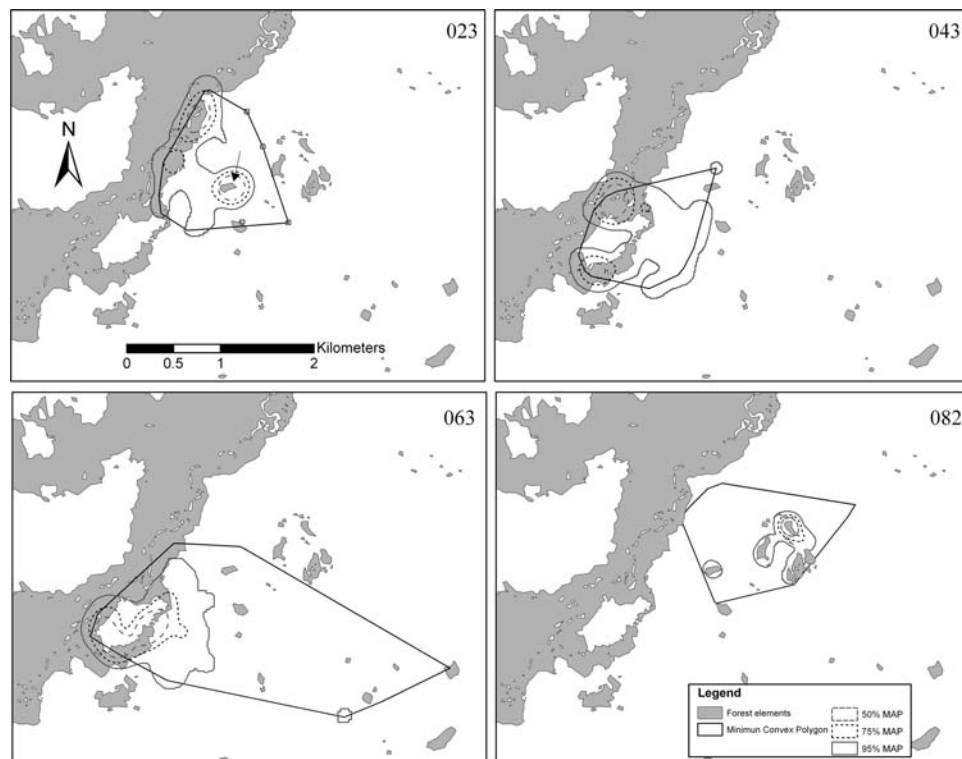


FIGURE 1. Home ranges of female *Sturnira lilium* bats 023, 063, 043, and 082. Forested elements in the landscape are depicted in gray and the savanna matrix is shown in white. The arrow points to the forest island where the bats were captured. The continuous black line denotes home range estimation calculated using the Minimum Convex Polygon method. Areas bordered by dashed lines represent Kernel Home Ranges with Minimum Area Probabilities (MAP). See Table 1 for details.

Telemetry Systems, Inc.). Individuals were followed until they returned to their capture roost. If a signal was lost at any time during the night we searched for the bat for up to 4 h before concluding the search. Most bearings were taken with observers following a specific bat continuously throughout the night. A primary station on a 15-m tower located in the savanna at the forest edge was also used to record bearings of bats using the forest. Bearings were taken every 5 min when bats were at stable locations (*i.e.*, feeding patches) or every minute during flight. Each bearing was taken with a hand-held compass and was read to the nearest degree. The position of the observer when the bearing was taken was recorded using a GPS Garmin 12 unit. Time and signal strength were also recorded for all bearings. The majority of nighttime positions of bats were calculated from single bearings, and distance was estimated from signal strength. Relationship of signal strength to distance was calibrated experimentally in the field at standardized gain settings. Because our goal in this study was to identify which landscape elements bats were using and whether they were moving among these elements, precise positions of bats within a habitat were not required. Rather, we focused on whether bats were in forest islands, continuous forest, or savanna. Positions were readily discernible given the distance between landscape elements (*i.e.*, forest and forest islands) and maximum signal alternation. In cases when bats did not return to the capture roost, we searched for the alternate roost the next morning. When a signal was detected, we attempted to locate the exact location of the alternate roost site.

We created a digital map of the study area using aerial photographs from 1993 that were georeferenced with known ground locations. This map depicted all forested landscape elements with an area over 0.1 ha. Positions for each bat were plotted using ArcView[®] 3.2. (ESRI Software). Movement patterns of *S. lilium* were examined using the Animal Movement Analyst Extension for Arcview[®] GIS (AMAE version 2.04 developed by Environmental Systems Research Institute, Inc., Redlands, California, U.S.A.). Home range was calculated using a fixed kernel home range utilization distribution and an *ad hoc* calculation of the smoothing parameter executed by the AMAE (Worton 1989, Hooge *et al.* 1999). For this study we set the Kernel Home Range to yield 95, 75, and 50 percent Minimum Area Probabilities (MAP). Additionally, home range was estimated using the Minimum Convex Polygon (MCP) method. Although this method is not generally recommended to estimate home range because it does not assess probability of occurrence and because usually the home range will increase as the number of relo-

cations increases (hence is subject to underestimation of home range at sample sizes below 50), it is useful to visually assess the potential area visited by each bat. Finally, we also examined movement paths per individual-night to determine routes followed by each bat on a given night.

RESULTS

We used 575 position determinations from the four *S. lilium* females to estimate home range size, core areas, and individual movement patterns. Kernel home ranges among individuals varied from 36.5 to 190.7 ha, whereas MCP ranged from 123.2 to 408.6 ha (Table 1). The mean long axis across the kernel home ranges for all bats was 1323.8 m and the range was 795.4–1716.3 m.

All four females included both continuous forest and forest islands in their home range (Fig. 1). During the study period, female 082's home range was mostly limited to forest islands and savanna, but the area illustrated by the MCP confirms that female 082 did fly into, at least, the edge of the continuous forest.

The core areas of activity (50% MAP) varied from 2.9 to 22 ha representing 6–12 percent of the kernel home ranges (Table 1). Use of continuous forest or forest islands as core areas varied among the four individuals. For example, female 023 had two disjunct core areas: one in the forest island that contained the day roost, and the other within the continuous forest at *ca* 800 m from the day roost. Similarly, two core areas are shown for female 043, both located in the continuous forest and separated by *ca* 800 m (from their midpoint). One core area, located in a forest island 900 m from the island with the day roost, is shown for bat 082. From the 75 percent MAP, it is evident that this individual (082) also actively used at least three other forest islands; one corresponding to the island containing the day roost, whereas the other two were *ca* 450 and 750 m from the day roost. Finally, one core area is shown for female 063, which encompasses savanna and the edge of the continuous forest. Core areas and home ranges overlapped among all four females (Table 2), which likely reflects overlap in resource use.

In general, there was high nightly consistency in the use of foraging areas. By plotting the cumulative home range (MCP) size against tracking time (for bats for which we had at least five tracking nights), we were able to determine how stationary or mobile bats were. Females 082 and 063 showed a rather stable home range,

TABLE 1. Minimum area probabilities (MAP) and Minimum Convex Polygon (MCP) areas of *Sturnira lilium* at Beni Biological Station-Biosphere Reserve in July 2001.

| Bat ID | Number of nights followed | Number of independent positions | Kernel home range and core-area use (ha) | | | | MCP area (ha) |
|--------|---------------------------|---------------------------------|--|---------|---------|------------|---------------|
| | | | 95% MAP | 75% MAP | 50% MAP | Total area | |
| 023 | 6 | 66 | 94.2 | 29.7 | 12.3 | 136.2 | 139.6 |
| 063 | 6 | 273 | 124.1 | 44.6 | 22.0 | 190.7 | 408.6 |
| 043 | 4 | 62 | 128.3 | 26.4 | 10.9 | 165.6 | 123.2 |
| 082 | 7 | 174 | 27.9 | 5.7 | 2.9 | 36.5 | 152.2 |

TABLE 2. Areas of kernel home range and core-area overlap among four individuals of *Sturnira lilium* at Beni Biological Station-Biosphere Reserve during July 2001.

| Bat ID | % Kernel home range overlap | | | | % Core area overlap | | | |
|--------|-----------------------------|-----|-----|-----|---------------------|-----|-----|-----|
| | 023 | 063 | 043 | 082 | 023 | 063 | 043 | 082 |
| 023 | — | 14 | 10 | — | — | — | — | — |
| 063 | — | — | 77 | — | — | — | 17 | — |
| 043 | — | 67 | — | — | — | 82 | — | — |
| 082 | 13 | — | — | — | — | — | — | — |

Table should be read as follows: 14% of female 023's home range overlapped with the home range of female 063. Female 043 utilized 82% of female 063's core area.

sticking to a certain foraging pattern for six nights and then, in case of female 063, suddenly increasing the home range size on the seventh night. Conversely, the home range of female 023 showed a constant and slow increase with number of tracking nights (Fig. 2).

All four females moved freely across the landscape. On individual nights, bats would visit both the continuous forest and the forest islands, often crossing the savanna matrix (Fig. 3). The maximum distance traveled in a straight line within a single night was *ca* 3 km, by female 063 between the forest island where her alternate day roost was located (1.9 km from the capture roost), and the continuous forest where the feeding patch was located.

Here, we present some estimates on travel times, although we cannot accurately calculate flight speeds for all bats on all nights. These calculations are based on instances in which we knew with certainty that a bat flew directly from one known location to another. Overall, bats took approximately 1.5–2 min for 0.5 km flights and 3.5–4 min for 1 km flights, a speed of approximately 15 km/h.

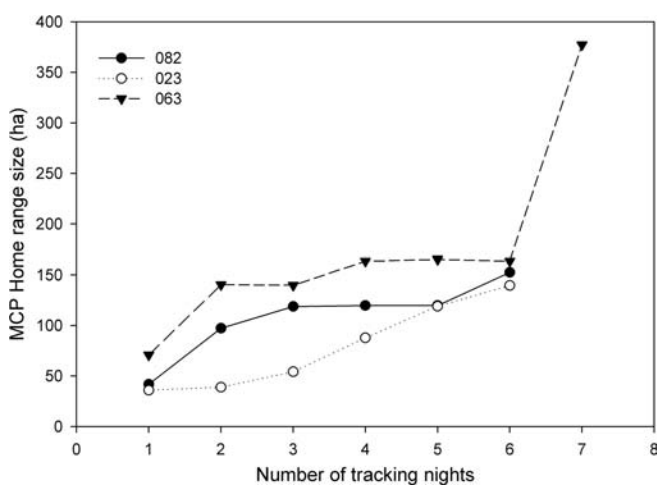


FIGURE 2. Cumulative home range size (MCP) for female bats 082, 023, and 063 with tracking time.

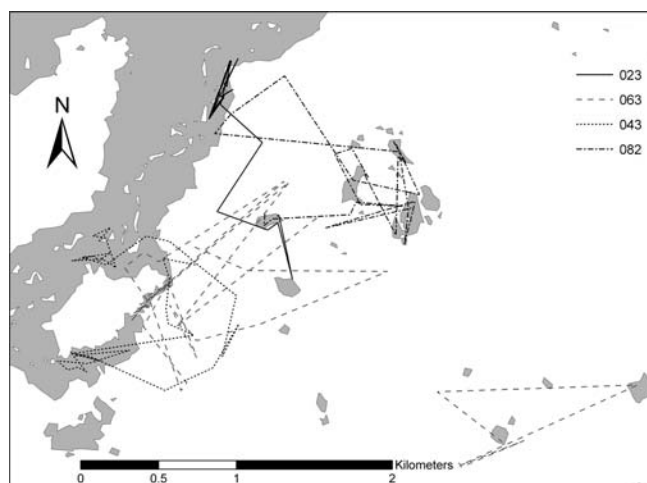


FIGURE 3. Examples of individual nightly movements of female bats 023, 043, 063, and 082. Note that both forest islands and continuous forest were visited on individual nights. Movements of female 063 show her visiting continuous forest and forest islands > 3 km away within a night (the break represents a time during which the signal was lost).

DISCUSSION

Despite the small sample size of this study, and the limited time frame (1 mo during the dry season), our results show that *S. lilium* can move freely among forest elements in the landscape while crossing a nonforested savanna matrix. This is consistent with results of other studies, which show that bats move among forest elements in a fragmented landscape (Estrada *et al.* 1993a, b; Bernard & Fenton 2003; Montiel *et al.* 2006). Furthermore, the data from this study provide evidence that individuals that permanently live in this naturally fragmented landscape can move between forest islands and forest during a single night.

Kernel home ranges of *S. lilium* in this study were 36.5–190.7 ha. Foraging distances over fragmented areas of other similar-sized bats in the Neotropics are comparable to those found in this study. For example, Bernard and Fenton (2003) found that home ranges of *C. perspicillata* and *C. brevicauda* over a naturally fragmented landscape varied between 155 and 320 ha. These estimates, which were calculated with a MCP-like method, are similar to the home range calculated for *S. lilium* using the minimum convex polygon (123.8–408.6 ha). Additionally, the maximum linear movement recorded by Bernard and Fenton (2003) for *Carollia* was 2.5 km, while the longest linear movement we recorded was *ca* 3 km. Hence, the results suggest that these three Neotropical species may have similar flight capabilities.

Although, we only radio-tracked nonreproductive females for this study, we do not think our estimates of the home range would change significantly by adding adult males. Other telemetry studies with frugivorous bats have shown that foraging range does not differ with sex (Winkelmann *et al.* 2000, Bonaccorso *et al.* 2002, Bonaccorso *et al.* 2006, Chaverri *et al.* 2007); hence, it is likely

that the home range sizes of adult *S. lilium* males are similar to those of females. Our estimate of home range size, however, may not accurately represent range size for pregnant or lactating females (e.g., Chaverri *et al.* 2007), or for bats during different seasons (Fleming 1988).

During this study, females foraged in continuous forest, forest islands, and savanna, and nightly commuting flights for all four individuals usually (ca 80%) included interhabitat movements among these landscape elements. This foraging pattern likely results from a nonrandom distribution of resources across the landscape. For example, at the time of the study, forest islands had trees with ripe fig fruits, and *Piper* and *Solanum* fruits were available in the savanna (Loayza 2002). In contrast, there was little fruit available in the continuous forest, although bats could have used that habitat for other resources (e.g., water, insects). Therefore, in fragmented habitats, where resources are patchy in space and time, bats, particularly frugivorous and nectarivorous species, may be compelled to use all available habitats to survive (Bernard & Fenton 2003, Montiel *et al.* 2006, Albrecht *et al.* 2007). In this sense, recapture data from a parallel study revealed that at least nine other species of bats (eight frugivorous, one nectarivorous) were used between one and four forest islands, as well as the continuous forest, during a 3-month period (Loayza 2002).

Individual bats typically used the same foraging areas on successive tracking nights. Foraging patterns for two of the females suggest that bats may forage in a feeding site regularly over several nights, and then change site once the resource has been depleted. This is consistent with field observations of the foraging site of female 082; a 25–30 m *Ficus* tree that was fruiting during the week we followed this female, but which no longer bore fruits by the end of the tracking period. Although inconclusive, this information supports the idea that home-range size is largely determined by dispersion of resources (Bonaccorso *et al.* 2002, Nicholls & Racey 2006).

Finally, the movement patterns of *S. lilium* across the savanna, likely promote seed exchange in this landscape both among the forested elements (e.g., continuous forest and forest islands) as well as the savanna. For example, in a parallel study looking at the diet of frugivorous bats in this landscape, we found that approximately 50 percent of the fecal samples collected at each site (forest island or continuous forest) had seeds of plant species that did not occur in the site (Loayza 2002). Although we did not quantify seed dispersal into the savanna, data from seed traps placed in the savanna at the same study site in different years contain large quantities of bat-dispersed seeds, especially by *Sturnira* (Arteaga *et al.* 2006; A. P. Loayza, pers. obs.). Together, these data contribute to the body of evidence showing that fruit-eating bats maintain connectivity and ecological processes in a fragmented landscape (Fahrig & Merriam 1985).

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