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Habitat use and movements of *Glossophaga soricina* and *Lonchophylla dekeyseri* (Chiroptera: Phyllostomidae) in a Neotropical savannah

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ABSTRACT. The greatest current threat to terrestrial fauna is continuous and severe landscape modification that destroys and degrades animal habitats. This rapid and severe modification has threatened species, local biological communities, and the ecological services that they provide, such as seed dispersal, insect predation, and pollination. Bats are important pollinators of the Cerrado (woodland savanna) because of their role in the life cycles of many plant species. However, there is little information about how these bat species are being affected by habitat loss and fragmentation. We used radio-tracking to estimate the home ranges of *Glossophaga soricina* (Pallas, 1776) and *Lonchophylla dekeyseri* Taddei, Vizotto & Sazima, 1983. The home range of *G. soricina* varies from 430 to 890 ha. They combine short-range flights of up to 500 m to nearby areas with longer flights of 2 to 3 km that take them away from their core areas. The maximum flight distance tracked for *L. dekeyseri* was 3.8 km, and its home range varies from 564 to 640 ha. The average distance travelled by this species was 1.3 km. Our data suggest that *G. soricina* and *L. dekeyseri* are able to explore the fragmented landscape of the Central Brazilian Cerrado and that they are likely to survive in the short- to medium-term. The natural dispersal ability of these two species may enable them to compensate for continued human disturbance in the region.

KEY WORDS. Bats; Brazil; Cerrado biome; home range; radio-tracking.

Habitat destruction and the associated degradation are the greatest threats to terrestrial fauna. Habitat loss impacts 86% of threatened mammals (Baillie *et al.* 2004), and there is no indication that landscape transformation is diminishing, especially in the Cerrado, which is a Brazilian biome that currently has a high level of industrial agriculture.

The Cerrado of Central Brazil, the most biologically rich savannah in the world, has been under serious threat for the last 35 years. More than 50% of its land has been lost to pasture and cropland (Klink & Machado 2005, Brasil 2009a). This rapid and severe landscape modification has threatened many species, which in turn has affected local biological communities and the ecological services that they provide, including seed dispersal, insect predation, and pollination. Long-distance pollen dispersal is important for plants, and bat pollinators are particularly well suited to provide this service (Fleming & Sosa 1994).

Bats are among the most important pollinators of the Cerrado because of their roles in the life cycles of many typical cerrado *sensu stricto* plant species, such as *Caryocar brasiliensis* Cambess., *Bauhinia holophylla* Steud., *Hymenaea stigonocarpa* Mart and *Luehea grandiflora* Mart. & Zucc. (Bobrowiec & Oliveira 2012). However, there is little knowledge about how these bat species are being affected by continued habitat loss and fragmentation in the region. There are also a number of gaps in our knowledge of the basic characteristics of the bat species of the Cerrado, including their diet, ecology, roosting requirements, behavior, and physiology (e.g., Bernard *et al.* 2011).

Radio-tracking is an important tool in the exploration of how native species perceive the structure of natural or altered landscapes in their habitats. Bats are seemingly unaffected by small changes in landscape structure because of their ability to fly, but contradictory results have been reported in the literature (Fenton 1997, Gorrensen *et al.* 2005). Part of this contradiction can be explained by the species-dependent nature of responses to landscape change (Gorrensen *et al.* 2005). Avila-Cabadilla *et al.* (2012), have shown that nectivorous bats are negatively associated with dry forest patches, while frugivorous bats are positively associated with riparian forest. Phyllostomid bats in savannah areas of the Brazilian Amazon were found by radio-tracking to have ranges of 0.5 to 2.5 km, which demonstrates interspecific differences in flight ability (Bernard & Fenton 2003). In contrast, phyllostomids in French Guiana and Panama were reluctant to traverse open spaces that composed a water matrix (Cosson *et al*. 1999, Albrecht *et al*. 2007). Therefore, the type of matrix has an impact on flight behavior. The perception of landscape fragmentation may also vary among individuals and species (Gorrensen *et al*. 2005), especially in regions that are naturally composed of a mosaic of different phytophysiognomies (see Montiel *et al*. 2006, Loayza & Loiselle 2008), such as the Cerrado (woodland savannah) (Eiten 1972).

We do not know how bats are responding to the anthropogenic changes that are occurring in the Cerrado biome. The use of radio-tracking studies may contribute to the understanding of how pollinator bat species are affected. Data on the home range and habitat use of a given species can be applied to determine its dispersal capacity, which indicates the ability of that species to utilize and survive in a fragmented landscape (Lima *et al*. 2012). This information can be used to establish conservation strategies for bat species, such as defining minimum acceptable distances between roosts and feeding areas, or determining the optimal quality of the ecosystems that they inhabit. We therefore used radio-tracking to investigate habitat use and movements of two small, primarily nectivorous phyllostomid species, Dekeyser's nectar bat – *Lonchophylla dekeyseri* Taddei, Vizotto & Sazima, 1983 –, and Pallas' long-tongued bat – *Glossophaga soricina* (Pallas, 1776). The two species are similar in size and diet (both eat pollen, fruits and insects) but differ in abundance. We hypothesize that the home range of the less abundant species (*L. dekeyseri*) is more restricted than that of *G. soricina* because it avoids crossing altered areas. Thus, we expect that the home range and the mean flight distance of *G. soricina* is greater than that of *L. dekeyseri*.

MATERIAL AND METHODS

The study was conducted in the Roncador Ecological Reserve (RER – 15°56'S, 47°53'W), which is 35 km south of the capital Brasília, and near the Sal Fenda cave (SFC – 15°30'35"S, 48°09'59"W) in Brazlândia, which is 45 km east of Brasília (Fig. 1). Spaced thorny trees (3 to 8 m tall) that are surrounded by smaller bushes and grasslands known as the cerrado *sensu stricto* characterize the vegetation in both areas. (The cerrado is a phytophysiognomy and Cerrado is the biome). The rainy season lasts from October to April, and the dry season lasts from May to September. The average temperature is 22°C, and the average annual rainfall is approximately 1,500 mm (Eiten 1994).

Brazlândia is within the Cafuringa Area of Environmental Protection (APA Cafuringa, 46,000 ha), which contains some of the last remaining native grasslands in the region and several limestone caves in the Distrito Federal itself (Baptista 1998). Sal Fenda is the largest granite cave in the Distrito Federal and is located at 840 m above sea level. There is an extension of the cave that has an elevation of 865 m. The original cerrado vegetation that surrounded the cave has been heavily deforested and replaced by pastures and degraded semi-deciduous

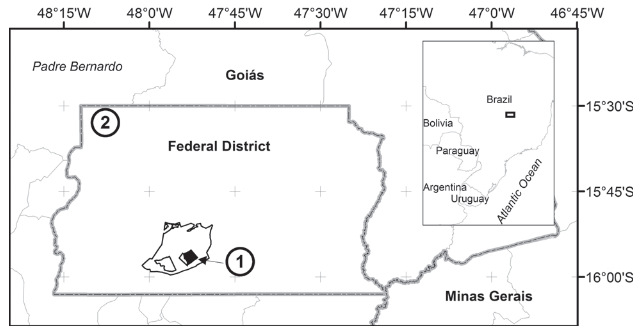

Figure 1. Location of the study sites in the Distrito Federal. The number "1" indicates the Reserva Ecológica do Roncador (RER) within the Área de Proteção Ambiental Gama-Cabeça do Veado, and the number "2" indicates the location of the Sal Fenda cave.

forest. The RER is surrounded by two other reserves, the Ecological Station of Brasília's Botanical Garden (JBB) on its northeastern border and Brasília University's Farm Água Limpa (FAL) on its southeastern border. These reserves together form a single large continuous tract of cerrado (*sensu stricto*). Nearly 75% of the RER's 1,350 ha are covered by this cerrado, with a heterogeneous landscape that is composed of smooth slopes and is crossed by small rivers and streams.

We defined a polygon of approximately 20 x 15 km (approximately 30,000 hectares) around each study site (RER and SFC) to assist in evaluating the status of natural coverage. According to maps prepared in 2009 by the Center for Remote Sensing of the Brazilian Institute of Environment and Renewable Natural Resources (Brasil 2009b), the remnants of native vegetation cover in the RER area represented 71.2% of this polygon. There are 15 fragments in the polygon. The average fragment size is of 1163.1 ha, and there is an average distance of 138 m between them. Native remnants represented 52% of the SEC area. It has 16 fragments, with an average fragment size of 790.4 ha. The average distance between fragments in this area was 395.5 m. We calculated all measurements that presented here with the extension Patch Analyst 5.0 (Rempel *et al*. 2012) and ArcGIS 10.0 software (ESRI 2010).

Lonchophylla dekeyseri is a small bat (10.7 ± 0.85 g; forearm length: 35.3 ± 8.5 mm) that is endemic to the Cerrado. It is threatened by extinction ("Endangered" according to the Brazilian Ministry of the Environment and "Near Threatened" according to the IUCN Red List) (Brasil 2003, IUCN 2011). This species is still relatively unknown and began to receive more attention only after its inclusion in the official list of Brazilian endangered species. In contrast, *G. soricina* (10.6 ± 1.7 g; forearm length: 35.4 ± 1.4 mm) is found from northern México to southern Argentina, including Jamaica and other islands near the northern coast of South America (Alvarez *et al*. 1991). This widespread species is not at risk of extinction and occupies a large variety of habitats, ranging from arid-subtropical thorn forest to tropical rainforests and savannahs, from sea level to 2,600 m elevation (Alvarez *et al*. 1991). Both species feed on insects, fruits and flower parts in addition to pollen and nectar. The known food sources of these bats include the pollen of several Cerrado plant species, including *Hymenaea stigonocarpa* Mart, ex Hayne, *Bauhinia brevipes* Vogel, *Bauhinia cupulata* Benth., *Bauhinia multinervia* (Kunth) D.C., *Bauhinia megalandra* Griseb., *Bauhinia pauletia* Pers., *Bauhinia ungulata* L., *Bauhinia rufa* (Bong.), and *Luehea speciosa* Wild. (Gibbs *et al*. 1999, Gribel & Hay 1993, Heithaus *et al*. 1975, Hokche & Ramírez 1990, Ramírez *et al*. 1984).

From 6-9 September 2005, four *G. soricina* individuals (one male, three females) were captured at RER, and from 10-12 October 2005, 10 *L. dekeyseri* individuals (five males, five females) were captured at the entrance of the Sal Fenda cave. All of the bats were captured with mist nets that were set around flowering pequi trees (*C. brasiliensis*). Radio transmitters (model LB-2, Holohil, Carp, Ontario, Canada) that were compliant with the 5% mass limit rule (Aldridge & Brigham 1988) were glued to the backs of the bats with Skin-Bond glue. Three pairs of researchers who were in radio contact with each other tracked the bats. At RER, where only *G. soricina* was tracked, two of the tracking teams were stationed at the tops of two existing 8- and 12-m towers, while the third team was instructed to move around to improve signal reception (White & Garrott 1990, Mason & Hope 2014). At Sal Fenda, where only *L. dekeyseri* was tracked, two 6-m aluminum pole structures were constructed to hold one antenna each, and the third was mobile (White & Garrott 1990, Mason & Hope 2014).

The location of each tracking station was marked using the average function of a GPS device (Garmin ETrex). The receivers that were used were TRX-1000 models (Wildlife Materials, Murphysboro, Illinois, USA) paired with Yagi Three-Element Antennas (Titley Scientific, Columbia, Missouri, USA). The teams attempted to locate each bat and collect a location point for each individual at five-minute intervals over the tracking period. Three bearings (one per team) were required for a location to be recorded (White & Garrott 1990). A bat was considered stationary when three consecutive bearing measurements indicated the same position for an individual. Data on the frequencies, date, time, and direction of the strongest signal intensities were taken as positional bearings using a compass and were recorded for each bat (White & Garrott 1990, Mason & Hope 2014).

The trajectory of displacement for each of the bats was represented by the sum of the sequential movements of each individual. A movement corresponded to the distance that was covered between two points as measured by triangulation of the bearings (White & Garrott 1990, Mason & Hope 2014). It was therefore possible to obtain the pattern of dispersion for each bat at the end of a tracking session.

The average distance covered and the flight directions taken by all of the tracked bats were recorded and plotted on a map. The bats were tracked until their signals were lost. *G. soricina* individuals were tracked from approximately 18:00 to 03:00 h the following day, and *L. dekeyseri* individuals were tracked from approximately 18:00 to 05:00 h.

The home range for each individual was calculated using the 'Animal Movement' extension (Hooge *et al*. 2001) of the ArcView 3.3 software (ESRI 2002) and was based on minimum convex polygons (MCP) and 95% kernel estimators (Hooge & Eichenlaub 1997, Jacob & Rudran 2003, White & Garrott 1990). To estimate the type and prevalence of the habitats that were within the calculated home ranges, the polygons were plotted on a 30-m resolution, classified Landsat ETM+ satellite image (taken on August 2002) that contained three native vegetation classes (cerrado, grassland, and forest) and one altered class (grouped anthropogenic areas, such as pasture, crop, urban and deforested areas).

RESULTS

Two of the four tracked *G. soricina* individuals (one male and one female) disappeared immediately following their release, and their signals were not detected for the remainder of the study. The two remaining individuals (females #58 and #69) were tracked for seven consecutive days, resulting in 105 location records (Table I). Based on their MCPs, their home ranges varied from 427 to 893.6 ha (Fig. 2). Both of the tracked individuals combined short-range flights of up to 500 m, possibly to scan nearby areas, with longer distance flights of 2 to 3 km to reach areas that were more distant from the core. The two bats used different parts of their home ranges to different degrees. On average, the main habitat types that they visited were cerrado vegetation (49.7%), grasslands (6%), and gallery forest areas (14.0%, used just twice) (Table II). The bats crossed disturbed areas (pasture and crops) to reach native areas that were outside of the RER. Based on 27 movements, the maximum flight distance tracked was 3.8 km and the average distance was 1.5 km (SD = 0.9 km).

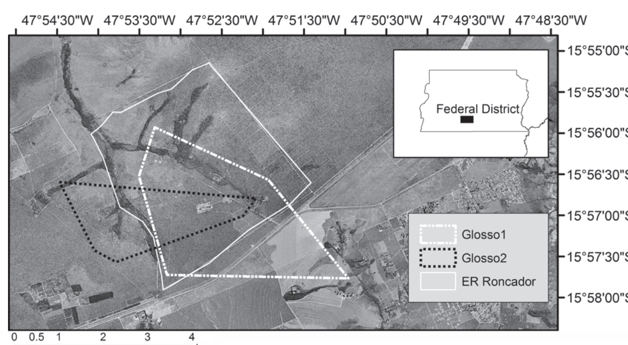

Figure 2. Home ranges of the two radio-tracked *Glossophaga soricina* bats (white polygons) in the Reserva Ecológica do Roncador (RER) (black polygon).

Table I. Basic data from each transmitter used to evaluate home range and movements of *Glossophaga soricina* and *Lonchophylla dekeyseri* in the Cerrado of Brasília, Brazil.

Species	Indiv.	Date	Time (min)	Valid points	Frequency
Glossophaga soricina	#58	6-8/Sep	580	85	151.140
Glossophaga soricina	#69	9/Sep	100	20	151.155
Lonchophylla dekeyseri	#59	10-Oct	600	15	151.161
Lonchophylla dekeyseri	#60	10-12/Oct	1800	35	151.180
Lonchophylla dekeyseri	#61	10-12/Oct	1800	15	151.198
Lonchophylla dekeyseri	#62	10-Oct	600	4	151.220

[1] The Time column indicates the total time that the individual was tracked in the study region.
[2] The Valid points column indicates the number of triangulated points that were used to calculate the individual's home range.

Table II. Composition of the native and anthropogenic environments within the home range of the tracked individuals of *Glossophaga soricina* at RER, Brasilia, Brazil.

Coverage	Indv. 58		Indiv. 62		Mean	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Pasture/grass	17.30	4.1	152.6	17.1	161.3	14.6
Forest	72.90	17.1	118.9	13.3	155.3	14.0
Cerrado s.s.	214.50	50.2	443.3	49.6	550.5	49.7
Grassland	14.20	3.3	58.8	6.5	65.9	6.0
Others (nonnative)	108.09	25.3	120.0	13.4	174.0	15.7
Total	427.00		893.6		660.3	

Six of the 10 *L. dekeyseri* individuals that were equipped with transmitters disappeared immediately after release and their signals were not recorded for the remainder of the tracking period. Two of the four remaining bats (females #60 and #61) were tracked for three consecutive nights, while the others (females #59 and #62) were tracked for a single night before their signals disappeared. The tracking of these four bats resulted in 69 location records (Table I). Three of the four tracked bats provided enough readings to estimate their home ranges (Fig. 3). Their average home range was 640 ha (SD = 704 ha) based on the MCPs and 564 ha (SD = 265 ha) based on 95% kernel estimates. The bats explored both fragments and forests, with an average of 53% of their home ranges (approximately 343 ha) being composed of cerrado and the remaining 47% of pasture (Table III).

In general, these home ranges were composed of irregular terrain, with drier forests along the steepest parts of the area and rock outcrops. Most of the native areas were in poor conservation condition, and there were cattle in several areas. Consequently, the understory in those areas was more degraded and more open than expected. Like the *G. soricina* individuals, the tracked *L. dekeyseri* individuals visited different parts of their home ranges during different nights. For example, one female (#60) visited the northeastern, northwestern, and northern parts of its home range and several points along the southern, southwestern and northeastern areas on four consecutive nights. The average movement distance of this species was 1.3 km (SD = 1.0 km), and the greatest distance flown was 3.8 km. The tracked bats exhibited two activity peaks, at approximately 19:00 and 02:00 h. The lowest activity occurred at approximately 21:00 and 04:00 h.

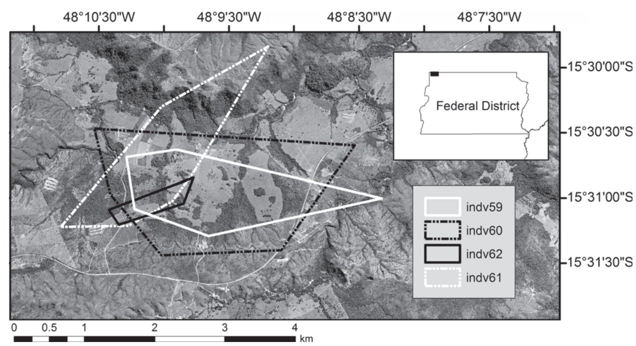

Figure 3. Home ranges of the four radio-tracked *Lonchophylla dekeyseri* bats in the northern region of the Distrito Federal.

Table III. Composition of the native and anthropogenic environments within the home range of the tracked individuals of *Lonchophylla dekeyseri* at Sal Fenda Cave, Brazlândia, Brazil.

Coverage	Indiv. 59		Indiv. 60		Indiv. 61		Mean	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Pasture	105.8	44.7	700.2	48.2	73.7	32.0	293.2	45.8
Forest	93.1	39.3	274.3	18.9	99.5	43.2	155.6	24.3
Cerrado s.s.	24.0	10.2	335.8	23.1	30.9	13.4	130.3	20.3
Grassland	13.7	5.8	143.6	9.9	16.8	7.3	58.0	9.1
Others (nonnative)	0.0	0.0	0.0	0.0	9.3	4.0	3.1	0.5
Total	236.6		1453.9		230.2		640.3	

DISCUSSION

Although the sample sizes in the present study are small and the measurements were limited to the dry season, the data support the hypothesis that the home range of *G. soricina* is larger than that of *L. dekeyseri*. The sample sizes do not permit more powerful statistical comparisons. The flight distances that were recorded for both species were similar. We therefore cannot confirm our hypothesis regarding differences in flight distance. Both species showed the same ability to visit natural vegetation patches in the study areas.

The characteristics of the vegetation structure of the study areas did not impose any significant impediment to radio signal transmission. This allowed us to detect signals at distances of up to 5 km. This detection distance was even greater when the antennas were positioned on a 10- to 12-meter-high fire observation tower. Other studies (McGuire 2010) have reported detection of signals from bats that were equipped with such small radios at distances of up to 12 km in estuarine regions.

Rothenwöhrer *et al.* (2011) state that the spatial and temporal activity of *Glossophaga commissarisi* Gardner, 1962 are closely matched to the local resource landscape, with high resource density allowing smaller home ranges, lower flight duration and thus reduced foraging costs. *G. soricina* and *L. dekeyseri* were much more mobile than expected despite their small body sizes. Both species are able to consume pollen, fruits and insects, suggesting that their broad home ranges reflect the wide spatial distribution of food or food quality rather than food scarcity. Previously published data show that bats of the savannahs of Brazil, Bolivia and Africa have smaller home ranges and flight distances than those that were observed in the present study. For example, the home range of *G. commissarisi*, at La Selva (Costa Rica) ranges from 7.4 to 23.9 ha (Rothenwöhrer *et al*. 2011), and that of *Artibeus watsoni* Thomas, 1901 is 3.6 ha (Rothenwöhrer *et al*. 2011). *Carollia perspicillata* (Linnaeus, 1758), a larger but still small frugivore, was found to have a home range of 155 to 320 ha in the savannah of the Brazilian Amazon (Bernard & Fenton 2003). Even when we compare data that were collected only from areas of open vegetation, the home ranges of our study exceed those that have been reported for larger species. In the Bolivian savannah, the home range of *Sturnira lilium* (E. Geoffroy, 1810) ranges from 36.5 to 190.7 ha (Loayza & Loiselle 2008), and the home range of *Megaloglossus woermannii* Pagenstecher, 1885, (which weighs less than 20 g) in the Lama Forest Reserve, southern Benin, West Africa, varies from 99.8 to 146.8 ha (Weber *et al.* 2009).

The larger home ranges that were observed in the present study for both *L. dekeyseri* and *G. soricina* might be explained by one of two different hypotheses. First, the ability to fly longer distances than those observed in other regions may be a consequence of the natural horizontal heterogeneity of the Cerrado. The Cerrado is a mosaic of different vegetation physiognomies, from grassland to forest, and it varies on the horizontal scale at the level of hundreds of meters (Eiten 1972, 1994). This characteristic of the Cerrado may encourage environmental plasticity of its bat species through the separation of habitat types. In this case, covering distances of 1 to 3 km to explore the surrounding area would be a natural circumstance for these animals, and may be sufficient to allow them to survive in landscapes with an intermediate level of fragmentation (such as the study site, where the fragments are separated by an average distance of 300-400 m).

Alternatively, these longer flight distances may be a result of the habitat fragmentation of the study areas. The bats may have to fly long distances to find suitable habitat fragments. The longer flight distances of both species are noteworthy regardless of the underlying cause.

Others have argued that the nectar-feeding phyllostomid bats of the subfamilies Lonchophyllinae and Glossophaginae are highly susceptible to extinction because many of these species are food and habitat specialists, roost in caves, show migratory behavior, and are already rare (Arita & Santos-del-Prado 1999). Others have found that these species are more resilient than other guilds to changes in land use (Willig *et al.* 2007). Our data indicate that *G. soricina* and *L. dekeyseri* are able to utilize the fragmented landscape of the Central Brazilian cerrado successfully. This ability may make them more likely to survive in the short run, but we still do not know how the quality of these different remnant fragments influences the long-term survival of both species. Nevertheless, populations of *L. dekeyseri* are declining in response to habitat loss and human disturbance (Aguiar *et al*. 2010), and this species has already been declared as endangered (Brasil 2003).

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