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Ecology

Population structure and reproduction of the hairy fruit-eating bat, *Artibeus hirsutus*, in central-western Mexico

Estructura poblacional y reproducción del murciélago frugívoro peludo, Artibeus hirsutus, *en el centro-oeste de México*

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Abstract

The hairy fruit-eating bat *Artibeus hirsutus* is endemic to Mexico and is considered a rare species. The little biological and ecological data on this species does not provide much information on its conservation status. The objective of this work was to evaluate the population structure and reproductive activity of a colony of *A. hirsutus* in west-central Mexico. We visited 12 times Isla Grande Atoyac, Jalisco. The individuals were captured inside the 2 caves with bucket traps or by hand directly from the cave roof, and with mist nets placed within the vegetation. We marked 77 individuals (67 adults, 5 juveniles, and 5 newborns), of which 34 were recaptured. The pooled recapture rate was 58.47%, and it increased from March to October and decreased in November and December. The minimum-number-alive value was higher in February (34) and lower in October (5), with an average of 21.1 individuals. Among the adult bats, 25.3% were males and 74.6% were females, with an overall female-biased sex ratio of 1:3.2. Sexual dimorphism was observed, with a significantly greater forearm length in females (55.7 mm) than males (54.4 mm). The study population showed a seasonal bimodal polyestry reproductive pattern.

Keywords: Chiroptera; Reproductive biology; Endemic species; Jalisco; Phyllostomidae

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Resumen

El murciélago frugívoro peludo *Artibeus hirsutus* es endémico de México y se considera una especie rara. Los datos biológicos y ecológicos de esta especie son insuficientes para conocer su estatus. El objetivo de este trabajo fue evaluar la estructura poblacional y reproducción de una colonia de *A. hirsutus* en el centro-oeste de México. Se realizaron 12 visitas a Isla Grande Atoyac, Jalisco, los individuos se capturaron dentro de 2 cuevas con trampas de cubeta o con la mano tomándolos directamente del techo, y con redes de niebla colocadas entre la vegetación. Se marcaron 77 individuos (67 adultos, 5 juveniles y 5 recién nacidos) con una tasa de recaptura promedio de 58.47%. El valor mínimo del número individuos conocidos vivos fue mayor en febrero (34) y menor en octubre (5), con un promedio de 21.1 individuos. Entre los murciélagos adultos, la proporción sexual fue de 1:3.2 sesgada hacia las hembras. Se observó dimorfismo sexual con una longitud del antebrazo significativamente mayor en hembras (55.7 mm) que en machos (54.4 mm). La población tuvo un patrón reproductivo poliéstrico bimodal estacional.

Palabras clave: Chiroptera; Biología reproductiva; Especie endémica; Jalisco; Phyllostomidae

Introduction

The hairy fruit-eating bat *Artibeus hirsutus* (Chiroptera: Phyllostomidae) is endemic to the Pacific slope of Mexico, from southern Sonora to Guerrero and from the lowlands of the Eje Neovolcánico Transversal of the Pacific Coast east to Morelos, at elevations ranging from sea level to 2,600 m (Webster & Jones, 1983). It prefers undisturbed tropical deciduous forests but is also found in surrounding anthropized habitats, such as fruit plantations, caves, mines, and houses (Arroyo-Cabrales & Álvarez-Castañeda, 2015; Ceballos et al., 2014; Téllez-Girón, 2014). Despite its large distribution, it is considered rare (low abundance; Téllez-Girón, 2014); however, it is not considered of high conservation concern, because of insufficient data available to evaluate its status (Téllez-Girón, 2014).

Since very little is known about the reproduction and population structure of *A. hirsutus* (Lumbreras-Ramos, 2012; Ortega et al., 2009; Sánchez-Hernández & Romero-Almaraz, 1995b; Watkins et al., 1972), it is important to gather relevant data to define and implement conservation and protection strategies (Ames et al., 2020). The aim of this research was to evaluate population structure and reproductive activity of a colony of *A. hirsutus* in central-western Mexico.

Materials and methods

We studied a colony of *A. hirsutus* at Isla Grande island, located in Sayula Lake, Atoyac, Jalisco, Mexico (19°59’56.44” N, 103°33’17.9” W; elevation 1,350 m; Fig. 1). Sayula Lake is a 26,400 hectare endorheic lake with a shallow water depth (60-90 cm) and saline soils, and approximately 20% of the area is seasonally flooded. The climate is semi-warm and subhumid (22 °C average annual temperature), and summer rains (800 mm average annual rainfall; Macías, 2004). Within Lake Sayula are 2 islands, Isla Grande and Isla Chica, 1 km apart. Both islands are extrusions relatively recent aphyric of labradorite and olivine, and andesites in lower proportion (Estrada-Faudón, 1983). Isla Grande is a 40 ha island dominated by thorn forests and tropical deciduous forests, with large fig trees as the most common trees (*Ficus insipida*, *F. goldmanii*, and *F. subrotundifolia*; Macías, 2004). Isla Grande is a private property in which human activities, such as tourism (wildlife watching) occurred at a low scale between 2014 and 2016. In 2015 a low-scale construction was started (for a thermal spa); but all the human activities on Isla Grande were canceled in 2016.

We found 2 bat roost caves on Isla Grande, approximately 50 m apart. Both caves are dry, with 1 chamber, and have a crack-type protrusion roof (Fig. 2A, D) (see Peñuela-Salgado & Pérez-Torres, 2015). Cave 1 is 2.5 m tall × 1.5 m wide × 10 m long (Fig. 2C) and has 2 entrances: the first one at floor level is 1.9 m × 0.8 m, and the second one in the roof is 1 m × 1 m (Fig. 2B). Cave 2 has 1 entrance and is 1.2 m tall × 3 m wide × 3 m long (Fig. 2E).

Sampling was done 1 day per month from January to December 2015. We captured all roosting *A. hirsutus* using bucket traps or by hand directly from the cave roof. Additionally, we set up 4 mist nets along paths for 4 h after sunset on 5 sampling sessions (June, July, August, November, and December). Sampling effort in caves were 30-60 minutes per cave per sampling session, and 960 meters-net-hours. The sex, age, right forearm length (mm), and reproductive condition of every captured bat was recorder. We classified individuals into 3 ages classes according to external features (hair), and development degree of the metacarpal gaps: *1)* newborns (cartilaginous phalangeal epiphyses, scarce hair, attached to mother), *2)* juveniles (cartilaginous phalangeal epiphyses, abundant

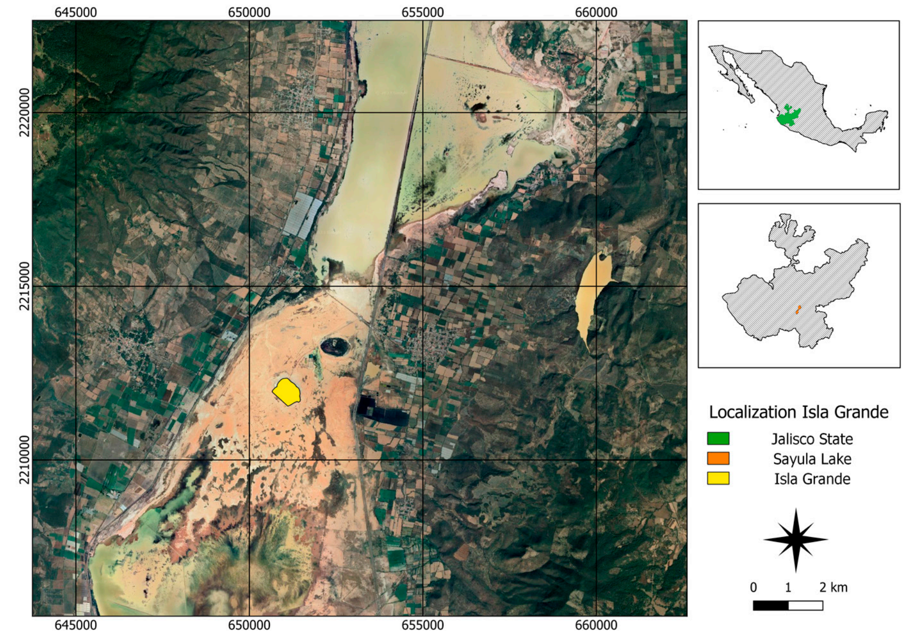

Figure 1. Location of Isla Grande at Lake Sayula, Jalisco, Mexico.

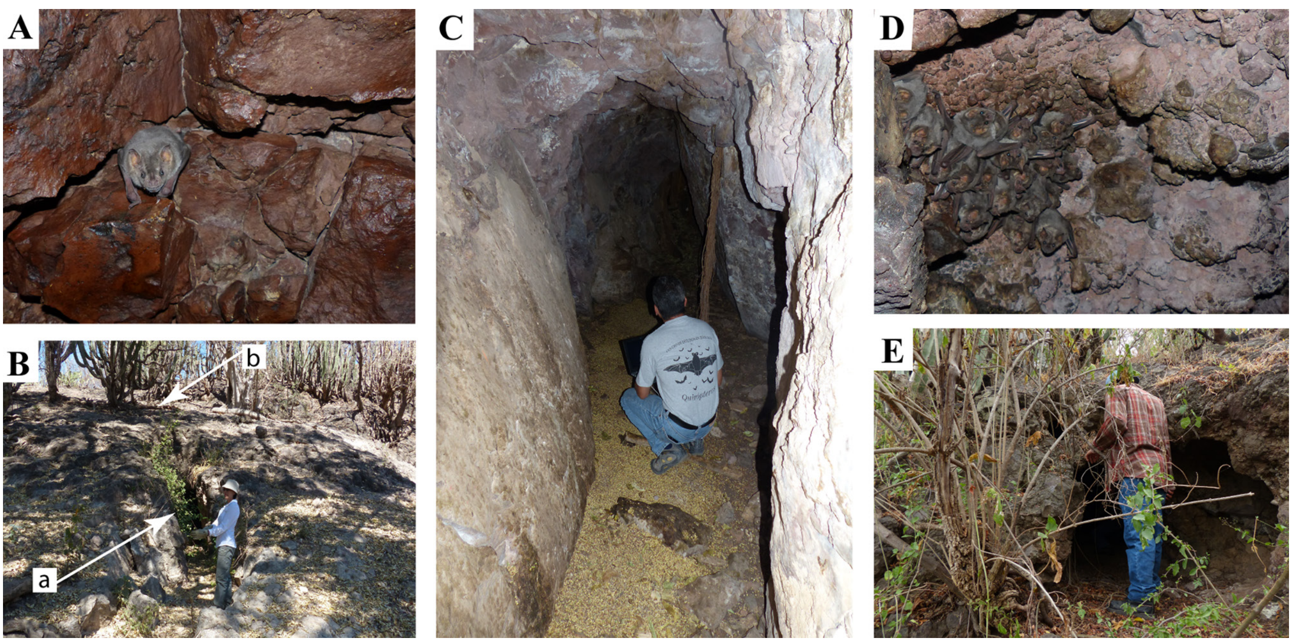

Figure 2. A) Cave 1, crack-with-protrusion roof, and individual of *Artibeus hirsutus*; B) cave 1: a) floor-level entrance and b) roof-level entrance; C) cave 1 interior; D) cave 2, crack-with-protrusion roof, and harem of *Artibeus hirsutus*; E) cave 2 entrance.

hair), and *3)* adults (complete ossification phalangeal epiphyses) (Handley et al., 1991). We classified female reproductive conditions into 4 classes: *1)* inactive (closed vagina with no embryos, hairy nipples), *2)* pregnant (with embryo), *3)* lactating (naked nipples with milk), and *4)* postlactating (naked nipples without milk). We measure crown-rump length of embryos. We classified males as either inactive (abdominal testes) or active (scrotal testes)

Table 1

Individuals per month and sex ratio of a hairy fruit-eating bat (*Artibeus hirsutus*) colony at Isla Grande (Atoyac, Jalisco, Mexico). c1 = Cave 1; c2 = cave 2; mn = mist net.

Month	Captures				Recapture (%)	MNA[a]	Sex ratio[b]
	total	c1	c2	mn			
January	17	17	0	-	0	17	1:1.12
February	27	-	27	-	0	34	1:4.66*
March	9	8	1	-	77.8	28	1:3.66*
April	10	6	4	-	60	29	1:3.66*
May	7	7	0	-	71.4	28	1:2.5*
June	19	13	0	6	78.9	32	1:2.5*
July	19	18	0	1	94.7	24	1:3.0*
August	8	6	0	2	75	17	1:1.8
September	18	17	1	-	72.22	20	1:1.8
October	4	4	0	-	100	5	1:0.25
November	8	3	0	5	62.5	8	1:0.6
December	11	2	0	9	9.1	11	1:1.75
Pooled mean	13.1	19.2	2.7	4.6	58.47	21.1	1:2.36*
± SD	± 6.8	± 5.9	7.7	3.2	± 35.35	± 9.6	

[a] Minimum number alive (Krebs, 1966). [b] Number of male per female (M:F). Asterisks denote significant departures from 1:1 ratio ($p < 0.05$).

(Handley et al., 1991; Kunz et al., 2009). We measure testis (length and width) of adult males and calculated the testis volume to explore variation among months (Myers, 1977). We marked all bats with numbered metal rings (Alloy Split Rings, 2.8-3.2 mm, Porzana Ltd.®) on the right metacarpal III and released them on-site after marking. We considered all *A. hirsutus* of Isla Grande belonged to the same colony because of the high mobility between capture sites (as evidenced by recaptures of marked individuals in roosts and mist nets). We used the minimum-number-alive estimator (MNA, Krebs, 1966) to estimate the monthly colony size and sex ratio. The percent of recapture and age classes was estimated with the monthly direct capture data. Chi-square tests were used to assess differences from a 1:1 sex ratio, and the Mann-Whitney U test was done to evaluate sexual dimorphism in forearm length. Kruskal-Wallis and Mann-Whitney U tests were performed to assess differences between embryos (length) and testicular volume. All analyses were performed using PAST 4.12b (Hammer et al., 2001). Bats were captured and handled following the guidelines of the American Society of Mammalogists (Sikes & The Animal Care and Use Committee of the American Society of Mammalogists, 2016).

Results

We captured and marked 77 individuals of *A. hirsutus*, which included 67 adults (17 males and 50 females), 5 juveniles (4 females and 1 male), and 5 newborns (4 females and 1 undetermined). Thirty-four (25 females and 9 males) were captured more than once, 31 individuals with 2-6 recapture events and 3 with 9 recapture events, for a total of 80 recaptures, and a total of 157 capture and recaptures. Males were recaptured more often (up to 9 times) than females (6 times). From the 157 capture and recaptures individuals, 101 (64.33%) were captured at roost 1, 33 (21.02%) at roost 2, and 23 (14.65%) with mist nets.

According to total capture and recapture data per month (individuals in cave 1 + cave 2 + mist net), the highest abundance was in February (27 individuals), June (19), July (19), and September (18). The lowest number of captured bats was recorded in October (4 individuals), May (7), and March (8). The percent of recapture was high, varying from 60% to 100% between March to November, and the pooled recapture rate was 58.47%. The MNA estimator indicated that the size of colony was larger in February (n = 34) and June (n = 32), with little variation among these months, and lower in October (n = 5) (Table 1).

Table 2

Statistics values of testicular volume per month of a hairy fruit-eating bat (*Artibeus hirsutus*) colony at Isla Grande (Atoyac, Jalisco, Mexico).

Month	n	Min	Max	Mean	SD
January[a]	8	85.12	232.67	177.27	52.30
February	1	215.06	215.06	215.06	0.00
March[b]	4	165.61	311.65	223.94	70.52
April	2	114.72	176.89	145.81	43.96
May[c]	5	53.25	175.62	119.10	47.91
June[a,b,d]	6	40.13	110.87	73.55	25.96
July	3	43.46	268.02	124.63	124.54
August[d]	4	158.17	265.07	202.19	51.43
September[c,d,e]	5	181.19	445.32	302.47	118.68
October[d]	3	168.74	210.16	187.12	21.10
November[d]	5	97.41	221.22	178.87	51.67
December[e]	3	39.02	146.20	103.88	57.03

The same letter denotes significant statistical differences (Mann-Whitney U tests, $p < 0.05$).

The colony formed harems. In roost 1 we found 2 main groups of 6-10 individuals and 2 smaller poorly defined groups (2-4 individuals). In roost 2 only in February, we found a harem composed of 26 females (25 pregnant) and 1 male. In total, the sex ratio was female-biased overall at 1:2.36 ($x^2 = 41.28$, $p = 0.000$), although in October and November, a male-biased sex ratio was observed (Table 1). The colony was mostly composed of adults (87%). Moreover, sexual dimorphism in forearm length was observed, with females (55.7 ± 1.49 mm) presenting significantly longer forearms than males (54.47 ± 1.65 mm; U =249, $p = 0.011$).

The reproductive pattern was seasonal bimodal polyestry. We found pregnant females in February, March, and July. The embryos were longest in March (n = 5, mean = 32.15, SD = 4.53) and July (n = 10, mean = 30.29, SD = 3.72) than February (n = 25, mean = 20.18, SD = 4.08); February was significantly different from March and July ($H = 24.79$, $p < 0.001$). Lactating females were observed in April (n = 4), August (n = 2), and September (n = 3); and postlactating females were captured in June (n = 6) and September (n = 1). In January (n = 9), November (n = 3), and December (n = 6), 100% of the captured females were inactive. We found evidence of 2 reproductive events in 11 females: 9 females with the first pregnancy occurring in February-March and the second pregnancy occurring in July, and 2 females pregnant in February-March (first pregnancy) and lactating in August-September (second pregnancy).

All captured adult males had scrotal testes, with testes volume largest in September (mean = 302.47, SD = 118.68) and smaller in June (mean = 73.55, SD = 25.96), with statistically significant differences between months ($H = 24.33$, $p = 0.004$; Table 2).

Discussion

In general, very little is known about population size, age, structure, and reproduction of the hairy fruit-eating bat. In Isla Grande, Jalisco, the number of captured individuals (n = 77) was similar to the one reported from cave El Salitre, in the state of Morelos, central Mexico (n = 89) (Ortega et al., 2009), but was higher than that reported at Grutas de Cacahuamilpa, in the state of Guerrero, Mexico (less than 50 individuals; Lumbreras-Ramos, 2012). The low number of captured individuals of *A. hirsutus* could be a characteristic of the colonies of this species (Tellez-Giron, 2014). However, we consider the colony size at Isla Grande could be higher because we cannot be certain if other undiscovered roosts occurred within the study site because fruit-eating bat colonies are usually composed of groups using different roost sites (Morrison & Handley, 1991; Sherwin et al., 2003). The fruit-eating bat *Artibeus jamaicensis* shows larger variations in colony size, from a few individuals up to 250 bats per roost (Goodwin, 1970; Ortega & Arita, 1999), while the great fruit-eating bat *A. lituratus* (cited as *A. intermedius*) is less abundant, with groups of 4-20 or more individuals (Sánchez-Hernández et al., 2016), which is more similar to the numbers reported for the hairy fruit-eating bat in our study.

According to minimum number alive MNA the colony size was higher from February to September and lower from October to December. The decrease in individuals in the last months could have been caused by a temporary disturbance due to the construction of a nearby rustic hut spa or because of stress from handling during capture. We visited the caves again in September 2017 and February 2021 and observed cave 1 with 30 and 60 individuals, respectively (Zalapa, pers. observ.). This increase could be due to the fact that after 2016 all tourism activities (photographic tours and spas) were abandoned.

The reproductive information indicates that hairy fruit-eating bats have a seasonal bimodal polyestry pattern, with births in April and August. Wilson (1979) reported pregnant females in February and April-September and lactating females in June and August-September throughout the distribution of the species. In addition, Anderson (1960) suggested that hairy fruit-eating bat lacks a restricted breeding season, which also coincides with the results of Findley and Jones (1965), who reported a continuous reproductive pattern based on pregnant females from February to September. They also found 3 males with sperm and 8 without sperm in the same sample; therefore, they concluded that spermatogenesis, copulation, lactation, and parturition were occurring at the same time. However, these studies were not carried out for an entire year, and no data were reported from October through January.

Neotropical frugivorous bats usually exhibit seasonal bimodal polyestry patterns, with newborns occurring in both dry and wet seasons, although they were associated with food availability (Racey, 1982; Wilson et al., 1991). Differences in reproductive patterns of other fruit-eating bats have been documented for the Jamaican fruit-eating bat (*A. jamaicensis*) and the great fruit-eating bat (*A. lituratus*) (Duarte & Talamoni, 2010; Fleming et al., 1972; Sánchez-Hernández & Romero-Almaraz, 1995a; Sánchez-Hernández et al., 1990; Stoner, 2001; Taddei, 1976; Tamsitt & Valdivieso, 1963; Wilson et al., 1991). Such variations might be associated with different weather patterns as well as with the distribution and availability of food resources (Happold & Happold, 1990). At Isla Grande, the hairy fruit-eating bat feeds almost exclusively on fig fruits (*Ficus* spp.), which are available throughout the year (Zalapa, pers. observ.).

The presence of harems with reproductively active males throughout the year supports the presence of a polygyny mating system, as previously reported for the species (Ortega et al., 2009). However, more information is necessary to determine whether hairy fruit-eating bat has female-defense polygyny or resource-defense (cave) polygyny mating system.

The hairy fruit-eating bat is the only endemic species of the genus *Artibeus* in Mexico, and it is the least known (Téllez-Girón, 2014). The paucity of information on the species makes this study relevant because it provides information that could be applied to conservation programs. Since the species exhibits a large variation in population parameters, we recommend carrying out local research that includes structure and reproductive patterns.

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