



Mastozoología Neotropical

ISSN: 0327-9383

ISSN: 1666-0536

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Sociedad Argentina para el Estudio de los Mamíferos  
Argentina

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Mastozoología Neotropical, vol. 25, no. 2, 2018, July-December, pp. 473-478  
Sociedad Argentina para el Estudio de los Mamíferos  
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## IMPACT OF ARTIFICIAL LIGHTING ON CAPTURE SUCCESS IN TWO SPECIES OF FRUGIVOROUS BATS (CHIROPTERA: PHYLLOSTOMIDAE) IN AN URBAN LOCALITY FROM THE VENEZUELAN ANDES

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**ABSTRACT.** Artificial light is becoming a major issue for bats because it affects critical activities such as foraging, reproduction, and communication. We assessed the effect of artificial lighting on *Artibeus lituratus* and *Artibeus jamaicensis* in a small secondary growth forest patch near a street subjected to unexpected illumination. Bats were captured in the forest patch using a 12-m long mist net. Results indicated a nearly six-fold, significant decrease in capture success after the street lamps were installed. Artificial light from street lamps functions as a “light barrier” that inhibits bats from conducting short and long-distance movements, which might have detrimental consequences for bats and the plants they disperse.

**RESUMEN.** Impacto de la luz artificial en el éxito de captura de dos especies de murciélagos frugívoros (Chiroptera: Phyllostomidae) en una localidad urbana de Los Andes venezolanos. La luz artificial se ha convertido en un problema grave para los murciélagos, porque está afectando actividades críticas que incluyen forrajeo, reproducción y comunicación. Evaluamos el efecto de la luz artificial en los murciélagos frugívoros *Artibeus lituratus* y *Artibeus jamaicensis*, en un pequeño parche de bosque secundario, cercano a una calle sujeta a una iluminación artificial inesperada. Capturamos a los murciélagos en el bosque secundario, empleando una red de neblina de 12 m de longitud. Los resultados indican que el éxito de captura disminuyó significativamente casi seis veces después de la instalación de los bombillos. La luz artificial de las lámparas funciona como “barreras u obstáculos de luz” que inhiben a los murciélagos de realizar movimientos de corta y larga distancia, lo cual podría tener consecuencias perjudiciales para los murciélagos y las plantas que ellos dispersan.

**Key words:** *Artibeus*, foraging, light pollution, mammals, Venezuela.

**Palabras clave:** *Artibeus*, contaminación lumínica, forrajeo, mamíferos, Venezuela.

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Bats are negatively affected by light even if the light source is natural and common. For example, bat foraging behavior is clearly shorter and restricted to earlier portions of the night during full moon (Tamsitt & Valdivieso 1961; Eckert 1974; Häussler & Eckert 1978; Morrison 1978; Börk 2006; Esbérard 2007; Mancina 2008; Santos-Moreno et al. 2010). Even though bats are adapted to natural light exposure, the use of artificial lighting has become a major issue for these nocturnal mammals (Stone et al. 2015; Rowse et al. 2016). The impact of artificial lighting on bats has been recently reviewed, and the conclusion is that street lighting not only causes light pollution and energy waste, but it also affects bats living near streets by altering critical bat behavior such as foraging, reproduction, and communication, among others (Stone et al. 2015; Rowse et al. 2016). For example, frugivorous bats may invest more time foraging when exposed to light, which can confound animal navigation (Stone et al. 2009; Lewanzik & Voigt 2014).

Although some open-space insectivorous bats seem to forage more actively around street lamps (Jung & Kalko 2010, 2011; Stone et al. 2015), the actual impacts of artificial lighting on frugivorous bats are still poorly understood. Frugivorous bats are negatively affected by artificial lighting because they tend to avoid well-illuminated areas, causing bat populations to move away from high-lit areas and into alternative darker areas. For example, Lewanzik & Voigt (2014) found that, under both free and captive conditions, the frugivorous bat *Carollia sowelli* showed reduced foraging success when exposed to light, reducing fruit harvesting and negatively impacting seed dispersal. Avoiding light forces bats to use alternative routes to reach foraging areas, thus affecting the amount of energy spent on flying from and to different foraging sites (Stone et al. 2009). Therefore, it could be predicted that artificial lighting may affect foraging activity, seed dispersal, and ultimately the fitness of frugivorous bats (Rowse et al. 2016).

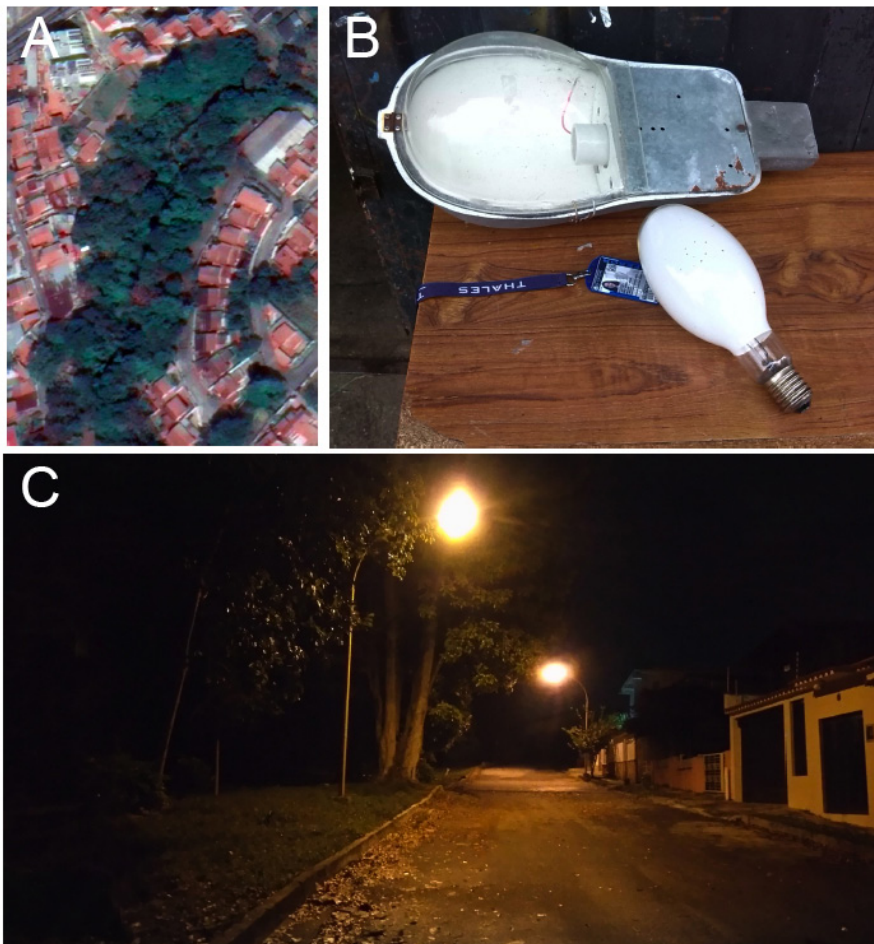
The most common type of streetlights used in urban, peri-urban, and rural areas are sodium lamps, which generate light via electric discharges through sodium vapor. There are

two types of sodium vapor street lights commonly used: Low Pressure Sodium (LPS) and High Pressure Sodium (HPS; Stone et al. 2015).

We have conducted several research studies in an urban area where we have captured two common frugivorous bats, *Artibeus lituratus* and *A. jamaicensis*, in great numbers (Muñoz-Romo 2003, 2006; Muñoz-Romo & Herrera 2003, 2010; Muñoz-Romo et al. 2008; Duque-Márquez & Muñoz-Romo 2015; Villalba-Alemán 2015). We noticed that a small street, located on a side of a second-growth forest patch (ca. 25 000 m<sup>2</sup>) within our study area, was illuminated with street lights that were installed the day before. We took this unique opportunity to test the effects of artificial light on frugivorous bats at this particular spot of our study area, for which we had long-term data and high capture success. We hypothesized that *Artibeus lituratus* and *A. jamaicensis* would be negatively affected, and capture success would decrease with the installment of street lights. To test this hypothesis, we decided to capture bats in this forest patch after artificial lighting was installed, and compared this data with capture success values before lights were installed.

*Artibeus lituratus* and *A. jamaicensis* are among the largest members of the subfamily Stenodermatinae (Davis 1984; Ortega & Castro-Arellano 2001). Both are common Neotropical frugivorous species that live in tropical forests where they often form small roosting groups in foliage (Ortega & Castro-Arellano 2001; Muñoz-Romo et al. 2008). Within our study area, we have long-term data that shows that *A. lituratus* uses modified palm leaves as diurnal roosts (Muñoz-Romo & Herrera 2003), and we know its trophic preferences (Muñoz-Romo & Herrera 2010), patterns of aggregation, roosting behavior, and group stability (Muñoz-Romo 2006; Muñoz-Romo et al. 2008).

Bats were captured in the small secondary growth forest patch near a street (**Fig. 1A**) located in an urban area called Urbanización Belensate in Mérida, Venezuela (08° 34' N, 71° 11' W, 1350 m a.s.l.). The study site is characterized by a mean annual temperature of 19 °C, and an annual average precipitation of 2044 mm (Camargo & Guerrero 1997). The rainfall regime is characterized by two periods



**Fig. 1.** (A) Image of the study site, a secondary growth forest patch on a side of a street ( $08^{\circ}34'N$ ,  $71^{\circ}11'W$ , 1350 m a.s.l.) from Urbanización Belensate in Mérida, Venezuela, obtained through Google earth; (B) high pressure sodium lamps used for artificial lighting (ID card used as size reference); (C) La Estancia street, subject to unexpected illumination.

of maximum rainfall, one in March-June with a maximum in May, and the other one between August and December, with a maximum in October. The dry season occurs between January and March (minimum January). The other short dry period occurs in July (Veillon 1989; Díaz de Pascual 1993). Vegetation of the study area includes unidentified species of *Ficus*, *Piper*, *Solanum*, *Cedrella*, and *Tabebuia*, as well as *Mangifera indica*, *Persea americana*, *Vismia baccifera*, and *Syzygium jambos*.

Bats were captured using a 12-m long mist net covering 2.5 m height (Kunz et al. 2009). We recorded standard body measurements (Brunet-

Rossini & Wilkinson 2009; Racey 2009), and marked individuals on the forearm (Kunz & Weise 2009) using aluminum wing bands (Gey Band & Tag Co., Norristown, PA, USA, size 4, Style 374) to avoid repeated sampling. All individuals were released. Bat capture, handling, and care followed the guidelines of the American Society of Mammalogists for handling mammals during research (Sikes et al. 2011).

Seven HPS light bulbs (Fig. 1B) were installed on seven 10-m post lamps (posts had been installed more than 10 years earlier, but never used) along a 160-m street segment (Figs. 1A and 1C). Posts are located every 20 m, bor-

dering the forest patch where individuals of *A. lituratus* and *A. jamaicensis* were captured. Capture success in the forest patch before the street lamps installation was assessed through 30 hours of bat sampling (eight sampling events covering the first half of the night) performed between June-September 2014 and February-September 2015. Thus, for comparative purposes, we performed the capture effort needed, from January to September 2016, to obtain the same number of individuals obtained before the bulbs installation. Since we noted that bats were scarce after lamp installation, we sampled continuously during 12-h long dark periods. To repeat accurately the same sampling conditions for both captures (before and after) we: (1) used only one 12-m long mist net; (2) located the mist net in the same location within the forest, 20-25 m away from the street; (3) avoided sampling on rainy and windy nights; and (4) sampled monthly during both full and new moon phases. We noticed that artificial light was only illuminating the street at night (Fig. 1C), whereas the mist net was invariably placed within the forest, under dark conditions. Thus, bats were unable to see the net.

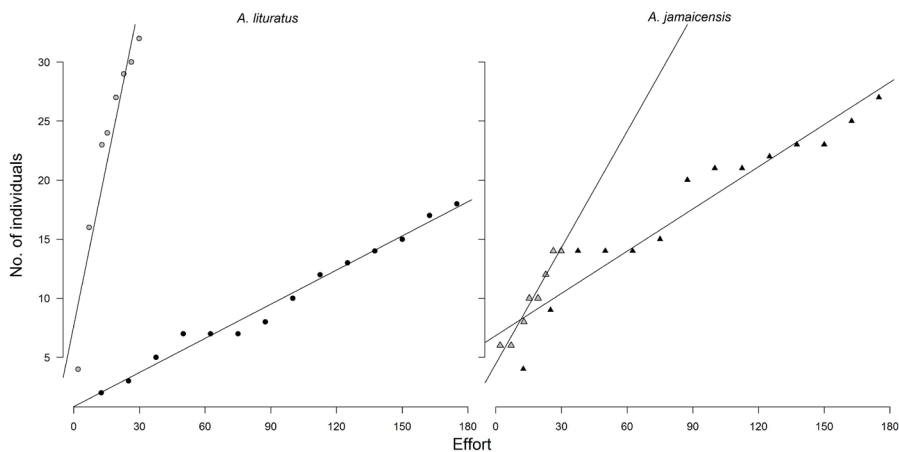
A total of 45 individuals (31 *A. lituratus* and 14 *A. jamaicensis*) were captured during 30 hours of sampling, before the installation of the HPS light bulbs (Fig. 2), while 45 individuals (18 *A. lituratus* and 27 *A. jamaicensis*) were captured during 175 hours of sampling, after the installation of the HPS light bulbs (Fig. 2). These results indicate that under no artificial lighting, bats were captured at a rate of 1.54 individuals/hour, whereas under artificial lighting, bats were captured at a rate of 0.26 individuals/hour. This means that capture success decreased almost six times as a consequence of street artificial lighting.

We performed an analysis of covariance (ANCOVA) using R language (R Core Team 2015) to compare the regression slopes and intercepts, testing the effect of the presence or absence of artificial light on the number of captures, while controlling for the effect of capture effort. The analysis indicates that artificial lighting has a significant and negative effect on bat captures ( $F = 17.444$ ,  $p = 0.000156$ ). As expected, capture effort has a significant effect on the number of

individuals captured ( $F = 7.174$ ,  $p = 0.010683$ ). Finally, the analysis also indicated that both *A. lituratus* and *A. jamaicensis* are equally affected by artificial lighting, since no significant difference was found between them ( $F = 0.043$ ,  $p = 0.837016$ ).

Our results indicate that street lighting affected both *A. jamaicensis* and *A. lituratus* because the effort needed to capture the same number of individuals (i.e., 45) increased from 30 h to 175 h. More replicates of this unique opportunity (i.e., sudden changes in light conditions near forest patches) are needed to confirm our findings. We also noticed that the proportion of individuals for each species changed before and after the bulbs installment, as more individuals of *A. lituratus* were captured before the light bulbs installment, while more individuals of *A. jamaicensis* were captured after light bulbs installment. This result suggests that the larger species of *Artibeus* could be more affected by artificial lighting, but this remains to be rigorously investigated. Results from this study are consistent with those found in an experimental study in which a group of captive females of *A. lituratus* required a longer time to detect food targets under a light intensity similar to twilight (Gutierrez et al. 2014). Our results further demonstrate that sudden changes in light intensity affect bat activity.

Lewanzik & Voigt (2014) postulated that artificial light from villages and street lamps act as "light barriers" that inhibit light-sensitive bats from conducting long-distance seed dispersal and pollination services between forest fragments, thus contributing to effective fragment isolation (Jung & Threlfall 2016; Lewanzik & Voigt 2014). *Artibeus lituratus*, an avid frugivore and important seed disperser, is able to perform long-distance flights (Arnone et al. 2016), and would probably be affected by artificial lighting (Gutierrez et al. 2014; Stone et al. 2009). Artificial lighting may affect ecosystem service provision by reducing bat-mediated seed dispersal (Rowse et al. 2016; Lewanzik & Voigt 2014), especially in areas where artificial light has been recently installed or around fragments in peri-urban areas that depend on long-distance flights from seed dispersers for plant turnover.



**Fig. 2.** Capture success of *A. lituratus* and *A. jamaicensis* before (empty symbols) and after (filled symbols) the installation of high pressure sodium light bulbs on La Estancia street, Urbanización Belensate, Mérida (Venezuela). La Estancia street is adjacent to a secondary growth forest patch where frugivorous bats forage. Effort measured in sampling time (hours).

Light pollution is now recognized as a key biodiversity threat (Stone et al. 2015; Rowse et al. 2016; Hölker et al. 2010), and is an emerging issue in biodiversity conservation, with important implications for policy development and strategic planning (Stone et al. 2015; Hölker et al. 2010). Given that removing street lights may not be practical or desirable for humans, a potential solution to minimize the negative effect of artificial lighting on bats is managing the duration and timing of lighting regimes to allow coexistence of both humans and wildlife. The appropriate lighting regime for an area will be site-specific and dependent on the nature of public use and type and amount of bat activity (Stone et al. 2015; Rowse et al. 2016).

**Acknowledgments.** For valuable field assistance, we thank X. Bustos, B. Porras, R. González, J. P. Tona, D. R. Martínez, E. Aguilar, C. Araujo, V. Quintero, O. Manrique, G. Barrios, and I. Lara. We are grateful to the subject editor, Luis Aguirre, Sergio Estrada-Villegas, and an anonymous reviewer for valuable comments and recommendations to improve the final version of this manuscript.

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