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ABSTRACT

In Costa Rica, bats are important nocturnal pollinators and seed dispersers. In this study, I investigated how diet type, species, levels of moonlight and moon phases, and nightly weather influenced the activity of bats. To do this, I used mist nets and an ultrasound detector for 11 nights to capture bats and record their species, sex, diet, and forearm length. Each night two to four mist nets were open from 17:30 to 20:00 and checked at 20 minute intervals. Nets were placed in Bajo del Tigre, the Monteverde Institute, San Luis, the Crandell Memorial Reserve, and La Estación Biológica Monteverde. I compared the time of each bat captured in terms of species and diet, and the number of individual bats captured per night to the corresponding moon phase, moon altitude, and weather. Of 23 total bats caught, 9 were different species. I found no clear species-specific activity patterns. When comparing data across different diet types (insectivore, frugivore, nectarivore), there was a clear pattern of insectivore activity peaking around 18:00, nectarivore activity around 19:00, and frugivore activity occurring throughout the mist netting period. This finding is corroborated by the fact that peak insect activity occurs immediately after sunset and is therefore the optimal feeding time for insectivores. The activity of nectar bats could be correlated with what time the desired flower opens. As for frugivorous bat, fruits are a widely available and stable food source which could explain their generalized activity. With regard to moonlight, more bats were captured during periods with less moonlight. This finding is described by “lunar phobia” which is exhibited in some animals due to decreased prey availability and higher susceptibility to predation. Finally, there was some indication that the previous night’s weather had an effect on bat activity the following night.

Patrones de Actividad de las Especies de Murciélagos Costarricenses

RESUMEN

En Costa Rica, los murciélagos son importantes polinizadores nocturnos y dispersores de semillas. En este estudio, investigué cómo el tipo de dieta, las especies, los niveles de luz de la luna y las fases de la luna, así como el clima nocturno influyeron en la actividad de los murciélagos. Para hacer esto, utilicé redes de neblina y un detector de ultrasonido durante 11 noches para capturar murciélagos y registrar su especie, sexo, dieta y longitud del antebrazo. Cada noche, dispuse dos o cuatro redes de niebla entre 17:30 a 20:00 de la noche y las revisé en intervalos de 20 minutos. Coloqué las redes en Bajo del Tigre, el Instituto Monteverde, San Luis Arriba y San Luis Abajo, la Reserva Crandell Memorial y La Estación Biológica Monteverde. Comparé la hora en la que cada murciélago fue capturado en términos de especies y dieta, y el número de individuos capturados por noche a la fase lunar correspondiente, la altitud de la luna y el clima.

De 23 murciélagos capturados en total, 9 fueron especies diferentes. No encontré patrones de actividad claros específicos. Al comparar datos entre diferentes tipos de dieta (insectívoro, frugívoro, nectarívoro), hubo un patrón claro de actividad insectívora que alcanzó un máximo alrededor de las 18:00, actividad nectarívora alrededor de las 19:00, y actividad de frugívoros durante todo el período de las redes de neblina. Este hallazgo se corrobora por el hecho de que la actividad pico de los insectos ocurre inmediatamente después de la puesta del sol y, por lo tanto, es el tiempo de alimentación óptimo para los insectívoros. La actividad de los murciélagos nectarívoros podría correlacionarse con a qué hora se abren las flores. En cuanto al murciélago frugívoro, las frutas son una fuente de alimento estable y ampliamente disponible que podría explicar su actividad generalizada. Con respecto a la luz de la luna, capturé más murciélagos durante períodos con menos luz de la luna. Este hallazgo se describe por la "fobia lunar" que se presenta en algunos animales debido a la menor disponibilidad de presas y una mayor susceptibilidad a la depredación. Finalmente, hubo algunos indicios de que el clima de la noche anterior afectó la actividad de los murciélagos la noche siguiente.

In Costa Rica, the most diverse group of mammals is the order Chiroptera, comprising of 109 bat species that represent more than half of the 216 other mammal species in the country (Wainwright, 2007). It is commonly known that bats are nocturnal creatures and therefore most active at night, but at what points during the night? Do all bats have similar periods of activity? Does activity differ between bats with specific diets? Is there a peak activity time for various species? Do bats change their activity as moon phases change? Is activity affected by moon illumination or altitude throughout a single night? How does bad weather affect a bat's activity?

One factor that influences activity is a bat's food source and how it's obtained. Chiropterans have very diverse diets, ranging from fruits, nectar and pollen, insects, other animals, or solely blood in the case of vampire bats. Some of these diets may be more accessible as compared to those available only during a specific time of day. Past studies found that in the case of insectivorous bats, most activity occurs in the first few hours after sunset when insect abundance is highest (Boonman et al., 2013). However, some species within the largest bat family in the new world, Phyllostomidae (Leaf-Nosed Bats), can be active all night (La Val, 1970). This may be due to having a food source that is more widely available and less time sensitive, such as fruit.

Contrary to the common misconception that bats are blind, many bats not only use echolocation but also vision for targeting their food source or foraging area (Gonzalez-Terrazas et al, 2016). When employed simultaneously, bats can use vision for locating large objects such as landmarks or trees, and echolocation for honing in on small objects such as prey or flowers (Gonzalez-Terrazas et al, 2016). Bats also use echolocation to maneuver their surroundings by making a sound and interpreting distance by hearing how quickly the sound bounces back (Cancel, 1998). Echolocation is done using ultrasonic frequency which ranges from 20 to 200 kHz and is too high for humans to hear (Cancel, 1998). Using specific devices that can detect ultrasonic frequencies and translate them into audible forms, echolocation calls could be monitored to determine the activity level of bats that are not easily seen or caught.

Another factor affecting bat activity is moonlight. The amount of light in the night sky increases as the moon becomes fuller, which may influence bats' prey availability and/or increase a bat's risk of being preyed upon (Lang et al., 2006). According to Morrison (1978), this idea may explain the trend of "lunar phobia" among bats, which is characterized by decreased activity with full moons and higher activity with new moons. For example, the Jamaican fruit bat (*Artibeus jamaicensis*) in Panamá reduces its time flying in bright moonlight by only taking long flights during the new moon period (Morrison, 1978). In addition, the Jamaican fruit bat was recorded foraging continuously during nights of the new moon period but remained in its roost when the moon peaked during the full moon period (Morrison, 1978). The exact reason for "lunar phobia" is unknown but is assumed to be species specific and correlated with prey availability and susceptibility to predation by snakes, birds, and some mammals (Lang et al., 2005).

Variations in resource abundance (especially temporal variation in food availability), weather, temperature, wind, and moonlight all potentially impact bats. How do activity patterns differ with these variables? How do activity patterns differ among bat species, bats with various diets, with levels of moonlight and across moon phases, and depending on nightly weather? Based on studies that found peak insect activity occurring immediately after sunset, I expected all insectivorous species to peak in activity earlier in the night and to be less active when the moon was full. Regardless of species, I expected larger bats to be more active than smaller bats during nights with a full moon. In a single night, I believed bat activity would increase when the moon's altitude was lower. I also predicted that fruit bats would have a continuous span of activity because fruits are present all night, whereas nectar bats may have a more distinct active period depending on when certain flowers open at night. Lastly, I expected that nights with more wind and rain would have less activity overall than nights with mild weather because bats might struggle to fly in strong wind and the mist nets are more easily detectable when weighed down by rainwater.

METHODS AND MATERIALS

To measure bat activity across a single night, I used mist nets to capture low flying bats and an ultrasound detector to listen for bats that fly higher and are less likely to be captured in the nets. I set up mist nets, untangled bats from the nets, and handled, identified, measured, and released bats. I set up mist nets in Bajo del Tigre (20 November), the Monteverde Institute (22 November), San Luis (24 & 25 November), the Crandell Reserve (26, 27, & 28 November), and La Estación Biológica Monteverde (29, 30 November, & December 2). I mist-netted for a total of 11 days and 1080 meters mist net hours.

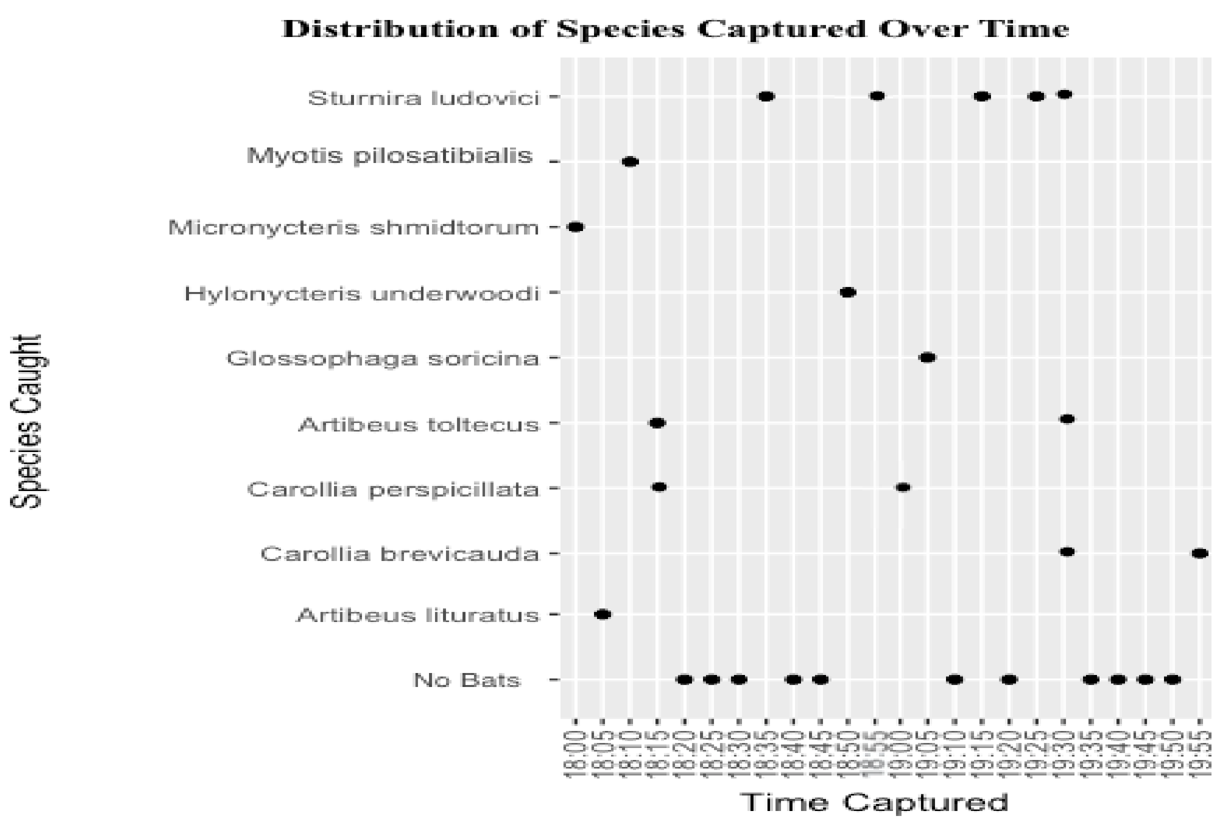
Each night we set up mist nets by 5PM, opened them around 5:30PM, and closed them around 8:00PM. I selected this time because bat activity begins after sunset and continues throughout the night. Nets were checked every 20 minutes. Each time I untangled a bat from a net, I recorded the time, general weather, the bat's species, sex, diet and forearm length (in millimeters), and categorized bats as small (30-40 mm), average (40-50 mm), or large (50+ mm) based on the forearm length measurement. Half way through the project I began checking for evening bat calls using an ultrasound detector at 60-70 kHz. I also checked for bat sounds (5 minutes at a time) in-between checking the nets.

After 11 days of mist-netting, I compared the time of each species caught, checked for peak activity times, and analyzed how species differed from one another. I also checked for a correlation between activity and moon data by comparing the number of individual bats captured per night to the corresponding moon phase, illumination, time of moonrise/moonset, and altitude of the moon every 20 minutes for a given night. Each phase lasts about one week so I considered the number of bats captured within that week to be related to the current moon phase. I did this with every night's data except November 5th because I did not gather data again until 15 days following that night which would leave out two complete weeks of potential bat captures and moon phases to find any correlation between.

In addition to the moon phases, I standardized the various weather conditions of each nights into four categories: good, fairly good, fairly bad, and bad. Good nights were clear and not too cold, fairly good was slightly windy, fairy bad was chilly and misty, bad was very windy and raining. I made a table with the date, number of individual bats caught, and nightly weather category. In order to look for a correlation between specific species and activity patterns, I graphed what time each species was caught from 5:30PM to 8PM, totaled from every night. In order to compare how activity patterns, differ depending on diet type, I graphed what time a species from the three diet types in the area was caught during the mist-netting period.

RESULTS

Figure 1. ("Distribution of Species Captured Over Time")



Of the 11 nights I mist-netted, 23 total bats were caught, there were 9 different species, and 1 unidentified bat was heard using the ultrasound detector. **Figure 1** contains the combined data points for nightly patterns of activity of each captured species across all 11 nights of mist-netting. There does not appear to be a clear pattern between species because many species appeared once or twice in the study period.

Figure 2. (“Bat Activity by Diet”)

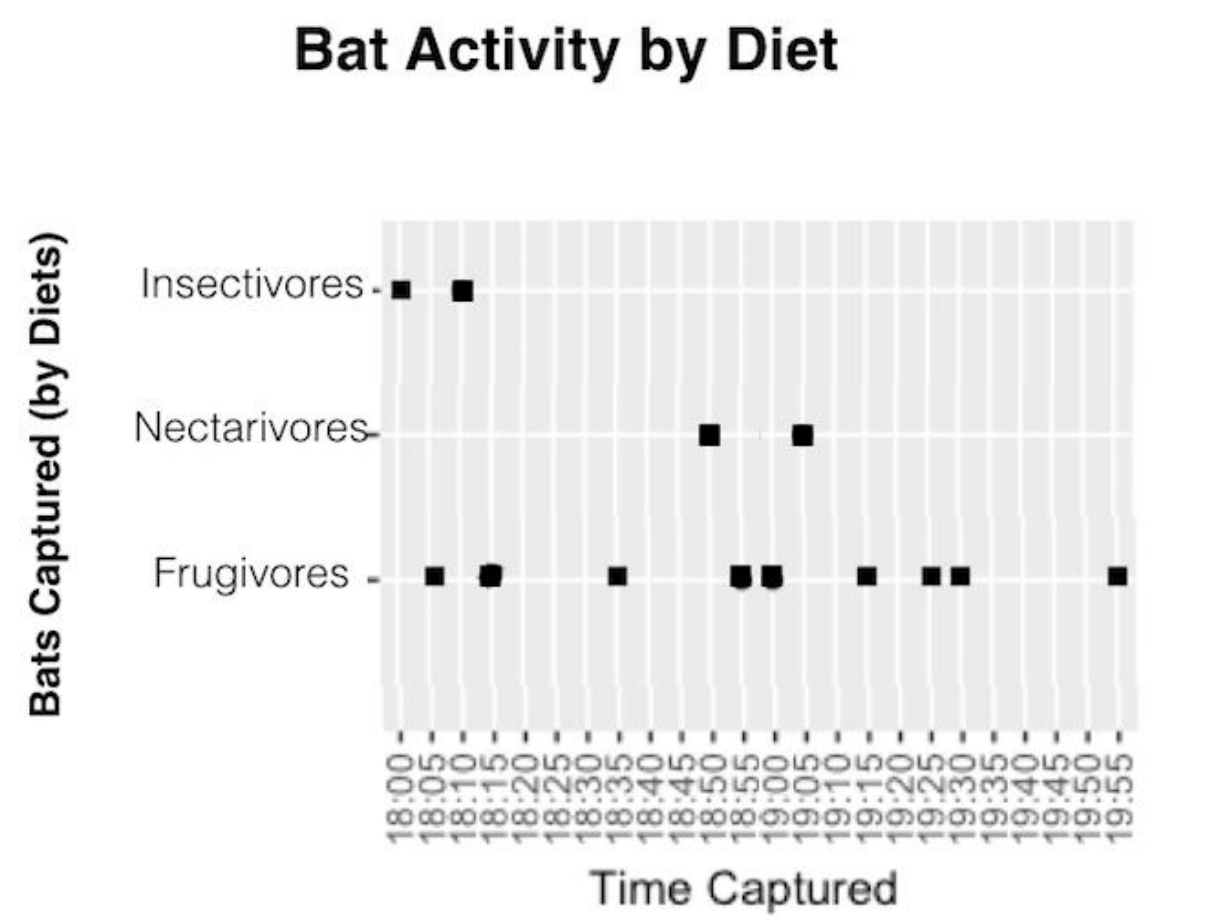


Figure 2 represents the combined number of bats captured in terms of their diet across all 11 nights of mist-netting. There are three distinct patterns that can be seen in this graph. More insect eaters were captured at 18:00 than the rest of the sampling period and more nectarivores were captured around 19:00 (Shapiro-Wilk test $p < 0.001$). Fruit-eating bats were captured the most often and consistently throughout the night.

Figure 3. ("Number of Bats Caught During Each Moon Phase")

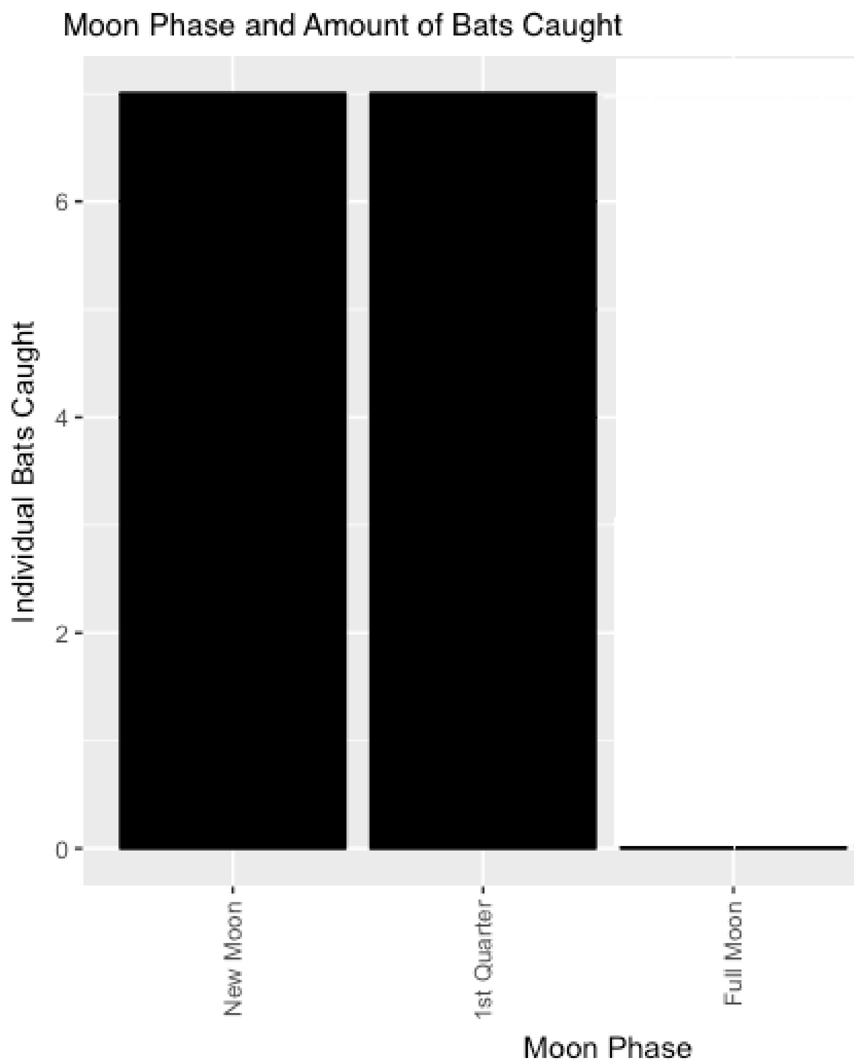


Figure 3 represents the number of individual bats captured during three consecutive moon phases: New Moon (17 - 24 November), First Quarter (25 November - 1 December), and Full Moon (2 December). As the figure shows, all 14 bats that were caught after the preliminary observations occurred during periods with less moonlight while not a single bat was caught during the full moon phase. I classified each phase as starting the day before the official moon period (for example, Full Moon started 2 December but the full moon occurred on 3 December) because the amount of light before a specific moon phase is more similar to that of the actual phase.

Table 1. ("Weather Categories")

Weather Category	Color Symbol
Good	
Fairly Good	
Fairly Bad	
Bad	

Table 2. ("Weather and number of bats caught each night")

Date (DD/MM)	Individuals Caught	Weather
20/11	4	
22/11	2	
24/11	1	
25/11	0	
26/11	4	
27/11	1	
28/11	1	
29/11	1	
30/11	0	
2/12	0	

The following tables show the dates, number of individual bats captured, and weather for each day. According to Table 2, bat activity may be correlated with weather from the previous night. For example, "bad" weather nights precede nights of low catches, even if that day's weather is more mild. In another example, the one night with "good" weather preceded the night with four bat captures which had "fairly bad" weather.

DISCUSSION

These results corroborate findings from the research mentioned previously, such as insectivorous bats' activity peaking earlier in the night due to the increased presence of insects (Boonman et al., 2013). Results similarly showed that nectar bats appear to be active in a short, specific period during the night, perhaps correlating to the blooming of a particular nocturnal flower. Future studies should consider swabbing these bats for pollen to attempt to identify which flowers they visit and what times they bloom. Related future studies could test if these flowers had any other visitors besides bats. In a continuation of this study, researchers could evaluate the specialization level of nectar bats and if they visit many flowers or just one/a few species. My results also reveal the lack of time specificity within fruit-eating bats which is shown in Figure 2. This is likely due to the fact that fruits are a more stable and stationary food source compared to time sensitive flowers and insects.

My results also reveal the phenomenon of "lunar phobia" among bats. Across the three lunar phases, there was a clear correlation of increased bat activity with decreased moonlight. Whether prey activity or threat of predation causes this trend, bats are less active when the moon is full regardless of body size (Lang et al., 2006). I originally hypothesized that larger bats may be more active during nights with more moonlight compared to small bats because they can be fruit eaters and fruit is not affected by moonlight. However, data showed that for nights with more than one capture, bats had very similar forearm lengths and there was a general decrease in bats caught when the moon was becoming fuller. Also, there did not appear to be any correlation between moon altitude and hourly bat activity. For example, *Sturnira ludovici* was the most frequently captured species and appeared continuously throughout the night, regardless of moon altitude. Future studies might continue mist-netting for a month to compare the number of bats caught over an entire lunar month and whether lunar phase or weather patterns influence bat activity more.

The most surprising result was increased bat activity during nights with fairly bad weather, as compared to nights with good weather. Moonlight could have caused this pattern rather than weather because as the weather was getting worse, the moon was becoming more full. Despite this, the results suggest it is plausible that bats determine their nightly activity based on the previous night's weather. The overall number of bats captured could also decrease as the climate gets colder. For example, in climates that reach freezing temperatures, some bats migrate or enter a state of torpor which slows down bodily functions and saves energy for periods of a few hours to a month ("Hibernate or Migrate").

About the single bat observed at 70 kHz with the ultrasound detector, I could not identify the species. However, the call occurred at 6:03PM and minutes later at 6:12PM a *Myotis pilosatibialis* bat was captured in the net and could very possibly have been the same bat that was heard making the calls.

Error in my results might stem from the bias of using mist nets and the non-specificity of ultrasound detectors. Mist nets only target bats that fly low enough to get caught and do not work well in storms due to heightened detectability when wet. Identifying bats heard on the ultrasound detector poses difficulties (and was impossible in this study), but knowing whether a bat is nearby based on its call still provides useful information.

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APPENDIX

Bats captured:

Family: Phyllostomidae, Subfam: Phyllostominae

Micronycteris shmidtorum (Schmidt's Large-Eared Bat)
Diet: Gleaning insectivore
Caught (date, time, location): 11/26 CR @ 6:00
FA: 34 mm
Sex: M

Family: Phyllostomidae, Subfam: Glossophaginae

Glossophaga soricina (Pallas' Long-Tongued Bat)
Diet: Nectarivore; sometimes pollen, fruit insects, flower parts
Caught (date, time, location): 11/24 SL @ 7:05
FA: 37mm
Sex: M
Notes: "Most active just after dusk and just before dawn" (LaVal, 149 - Murciélagos de Costa Rica).

Hylonycteris underwoodi (Underwood's Long-Tongued Bat)
Diet: Nectarivore; sometimes pollen, insects, and fruit
Caught (date, time, location): 11/29 EB @ 6:50
FA: 35 mm
Sex: M

Family: Phyllostomidae, Subfam: Carollinae

Carollia brevicauda (sowelli) (Silky Short-Tailed Bat). caught twice
Diet: Frugivore, occasionally insects
Caught (date, time, location): 11/5 EB by 7:30, 11/26 CR @ 7:55
FA: 40 mm, 40 mm
Sex: NA, M

Carollia perspicillata (Seba's Short-Tailed Bat). Caught twice
Diet: Frugivore, occasionally nectar and insects
Caught (date, time, location): 11/20 BT @ 6:15, 11/20 BT @ 7:00
FA: 40 mm, 39 mm
Sex: F, M

Family: Phyllostomidae, Subfam: Stenodermatinae

Artibeus lituratus (Big Fruit-Eating Bat)
Diet: Frugivore; occasionally nectar, pollen, leaves, and insects
Caught (date, time, location): 11/27 CR @ 6:05
FA: 67 mm
Sex: M

Artibeus toltecus (Toltec Fruit-Eating Bat). Caught three times
Diet: Frugivore
Caught (date, time, location): 11/5 EB by 7:30, 2x 11/20 BT @ 6:15
FA: 40 mm, 40 mm, 41 mm
Sex: NA, F, M

Sturnira ludovici (hondurensis) (Highland Yellow-Shouldered Bat). caught five times
Diet: Frugivore
Caught (date, time, location): 11/5 EB by 7:30, 11/22 MVI @ 6:55, 11/22 @ MVI @ 7:25, 11/26 CR @ 6:35, 11/26 CR @ 7:15
FA: 43 mm, 45 mm, 45 mm (juvenile), 44 mm, 47 mm
Sex: NA, F, M, F, M

Family: Vespertilionidae

Myotis pilosatibialis (formally M. keaysi) (Hairy-Legged Myotis)
Diet: Aerial insectivore
Caught (date, time, location): 11/28 CR @ 6:12
FA: 38 mm
Sex: M

Notes: 11/28 - likely the bat heard at 6:03 @ 70 kHz (insect eater)

Family	Subfamily	Species	Common Name	Diet	Caught (date, time, location)	Forearm Length (mm)	Sex	Notes
Phyllostomidae	Phyllostominae	Micronycteris shmidtorum	Schmidt's Large-Eared Bat	Gleaning insectivore	11/26 CR @ 6:00	34	M	
	Glossophaginae	Glossophaga soricina	Pallas' Long-Tongued Bat	Nectarivore; sometimes pollen, fruit insects, flower parts	11/24 SL @ 7:05	37	M	Most active just after dusk and just before dawn" (LaVal, 149 - Murciélagos de Costa Rica)
		Hylonycteris underwoodi	Underwood's Long-Tongued Bat	Nectarivore; sometimes pollen, insects, and fruit	11/29 EB @ 6:50	35	M	
	Carollinae	Carollia brevicauda (sowelli)	Silky Short-Tailed Bat	Frugivore, occasionally insects	11/5 EB by 7:30, 11/26 CR @ 7:55	40, 40	NA, M	
		Carollia perspicillata	Seba's Short-Tailed Bat	Frugivore, occasionally nectar and insects	11/20 BT @ 6:15, 11/20 BT @ 7:00	40, 39	F, M	
	Stenodermatinae	Artibeus lituratus	Big Fruit-Eating Bat	Frugivore; occasionally nectar, pollen, leaves, and insects	11/27 CR @ 6:05	67	M	
		Artibeus toltecus	Toltec Fruit-Eating Bat	Frugivore	11/5 EB by 7:30, 2x 11/20 BT @ 6:15	40, 40, 41	NA, F, M	
		Sturnira ludovici	Anthony's Bat; Highland Yellow-Shouldered Bat	Frugivore	11/5 EB by 7:30, 11/22 MVI @ 6:55, 11/22 @ MVI @ 7:25, 11/26 CR @ 6:35, 11/26 CR @ 7:15	43, 45, 45 (juvenile), 44, 47	NA, F, M, F, M	
Vespertilionidae		Myotis pilosatibialis (formally M. keaysi)	Hairy-Legged Myotis	Aerial insectivore	11/28 CR @ 6:12	38	M	11/28 - likely the bat heard at 6:03 @ 70 kHz (insect eater)