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# Effects of land use on foraging of insectivorous bats in pre-montane wet forest

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## ABSTRACT

Many bat species around the world are threatened because of habitat loss due to land development. This study looked at how foraging of insectivorous bats differed among four different localities including: agricultural, urban, and forested sites of two different elevations. Bio-acoustic recordings were done using an "Echo Meter Touch". Species richness was recorded throughout the sites. Overall bat foraging activity was measured by the amount of individual bat calls, total duration of bat calls per location, and a Shannon's index to compare activity between sites. A Chi-squared test was used to compare species richness, no significant differences were found between sites. I performed a modified t-test to compare the differences in H' values which resulted in a significant difference between all sites, except the low elevation forest and the urban sites. The Agricultural site has the highest richness (11 species) and bat activity index (H'=0.89), while the least anthropogenically disturbed site at the high elevation forest had the lowest species richness (4 species), and had the lowest bat activity index as well (H'= 0.20). Land developed for agriculture or urban use had greater or equal foraging activity than areas not developed, therefore human development has not negatively impacted the insectivorous bat community of Monteverde.

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# Efectos del uso del suelo sobre actividad de forrajeo de murciélagos insectívoros en bosque muy húmedo pre-montano

## RESUMEN

Muchas especies de murciélagos en todo el mundo están amenazadas por la pérdida de hábitat. Evalué la actividad de forrajeo de murciélagos insectívoros en cuatro localidades: sitios agrícolas, urbanas, y boscosas de dos elevaciones diferentes. Realicé grabaciones bio-acústicas con un "Echo Meter Touch" y estimé la riqueza de especies en esos sitios. La actividad de forrajeo de murciélago se midió por la cantidad de llamadas de cada individuo, la duración total de las llamadas de murciélagos por ubicación, calculando la actividad de cada especie mediante la fórmula del Índice de Shannon. Utilicé una prueba de ji cuadrado para comparar la riqueza de especies, sin encontrar diferencias entre los sitios. Apliqué la prueba de t modificada para comparar valores H´ de Shannon, encontrando diferencia significativa entre todos los sitios, excepto entre el bosque de baja elevación y los núcleos urbanos. El sitio agrícola tuvo la mayor riqueza (11 especies) y el mayor índice de actividad de murciélagos (H' = 0.89), mientras que el sitio menos perturbados en el bosque de mayor elevación tuvo la menor riqueza de especies (4 especies), con el índice de actividad de murciélagos más bajo (H '=0.20). Tierra desarrollada para uso agrícola o urbana tenía mayor o igual actividad de forrajeo de las áreas no desarrolladas, por lo tanto, el desarrollo humano no ha impactado negativamente en la comunidad murciélago insectívoro de la región de Monteverde. Por el contrario, este estudio sugiere que prefieren forrajear en tierra desarrollado.

In tropical ecosystems, anthropogenically altered environments can pressure native wildlife to alter their habitat use (Jung & Kalko, 2010). Developed areas can have an effect on the species composition and abundance of native wildlife for various reasons. However, some species have the capacity to adapt to human-induced environmental changes. Bat populations around the world have been threatened by habitat loss due to land development; yet, some species of aerial insectivorous bats have been shown to thrive in urban settings (Jung & Kalko, 2010). Patterns of species diversity and the factors that influence the structure of bat communities are important ecological aspects to monitor as human development expands. Understanding the effects development has on the local bat populations can help maintain their important ecological presence.

Costa Rica is home to approximately 110 species of bat, most of which are insectivorous. Neotropical insectivorous bats are able to forage in a variety of habitats that include developed areas (Laval and Rodriguez, 2002). In a study conducted in Panama, areas with artificial urban lighting resulted in higher insectivorous bat foraging activity (Jung & Kalko, 2010). In a study conducted in a Mexican coffee plantation, researchers were able to determine that the presence of insectivorous bats reduced arthropods by 26% (Williams-Guillen, 2008). By determining how different uses of land can influence the foraging activity of insectivorous Neotropical bats, then the effects of human development on their communities can be assessed.

The bat fauna of Monteverde has been extensively sampled by biologists, however the effects of urban development on community structure has not been assessed in the greater Monteverde area. For this study, the greater Monteverde area includes Canitas, La Cruz, Cerro Plano, and the Monteverde cloud forest which will be referred to as the Monteverde area from here on. With the exception of the cloud forest, the Monteverde area has experienced rapid development in the past 50 years (Nadkarni & Wheelwright 2000). Land use in this area varies greatly from primary and secondary forest, agricultural farms for monocultures and organic produce, and as urban development for homes and businesses. A large proportion of land in the Monteverde area that was once primary forest has undergone urban and agricultural development, such as coffee plantations, however a large proportion has also been restored to secondary forest. These changes in land use might affect the composition and abundance of the bat species that forage in those areas.

Different species of bats have different foraging behavior and habitat preference. I will evaluate foraging activity and the overall species richness of three habitat types including: agricultural, urban, and forested areas. I expect bat communities will change in composition when compared to different habitats. Some insectivorous bats might be more abundant in areas that are more developed and have more anthropogenic lighting because insects are more attracted to lit areas (Frank 2015) and prefer open edge habitat (Jantzen, 2013). Species that like to roost in large numbers, such as *Tadarida brasiliensis*, might also benefit from habitats closer to developed areas because they can utilize man-made structures to roost (Laval and Rodriguez 2002). Species that are gleaners, solitary roosters, or more sensitive to light pollution, such as *Myotis keasyi pilosatibialis,* might be more abundant in areas that are more secluded from human activity because developed structures are not the preferred foraging habitat and preferred prey species might be less abundant. Species richness is difficult to predict because each habitat might have pros for a certain species and cons for another. I also expect there would be species detected in forested areas that are not present in urban or agricultural areas. Comparing these sites will determine how the use of the landscape in the Monteverde area can affect where insectivorous bat species prefer to forage, thus assessing the impact that development can have on insectivorous bat communities.

## MATERIALS AND METHODS

Study Sites- This study was conducted during the spring of 2016 from May 10$^{th}$ to May 24$^{th}$. Bio-acoustic recordings were made at four pairs of sites (localities) in pre-montane and lower montane moist forest around Monteverde representing three habitat types: agricultural area, an urban area affected by anthropogenic lights and two forested areas (see Fig. 1). I took advantage of the darker nights when the lunar phase was a waxing crescent at the beginning of my study to first sample the more exposed agricultural area, then the forested areas and lastly the urban areas. Within each pair, sites differed from each other no more than 60 meters in elevation The site pairs at the agricultural, urban, and lower forested sites differed no more than 100 meters. However, the higher elevation forested sites had an average of 180 meter difference from the other three sites which could possibly be a factor that might affect the species composition and relative foraging activity (see appendix A). Each of the 8 sites was visited once and combined in pairs to represent the four sites mentioned above. Recordings at the agricultural site of Life Monteverde were sampled both in the coffee plots and organic garden at approximately 1280 m in elevation. The urban areas were conducted in Santa Elena and Cerro Plano in close proximity of street lights and infrastructure which ranged from 1330-1390 m in elevation. The placement of the recorder for these sites was within 10 meters of a paved road and was the most developed of sampled sites (see Fig 1). The two forested areas consisted of two different elevations: a forested area within the same elevation of the previous two sites (urban and agricultural) at approximately 1370 m in elevation, and a higher elevation forest which ranged from 1510-1540 m in elevation. The higher elevation forest was edge to cloud forest and chosen despite elevational differences because it represented the least anthropogenically developed area. Both set ups were on trails in closed canopy forest. The forest trails provide clear pathed corridors for flight, therefore trails are an ideal place to set bat recording equipment.

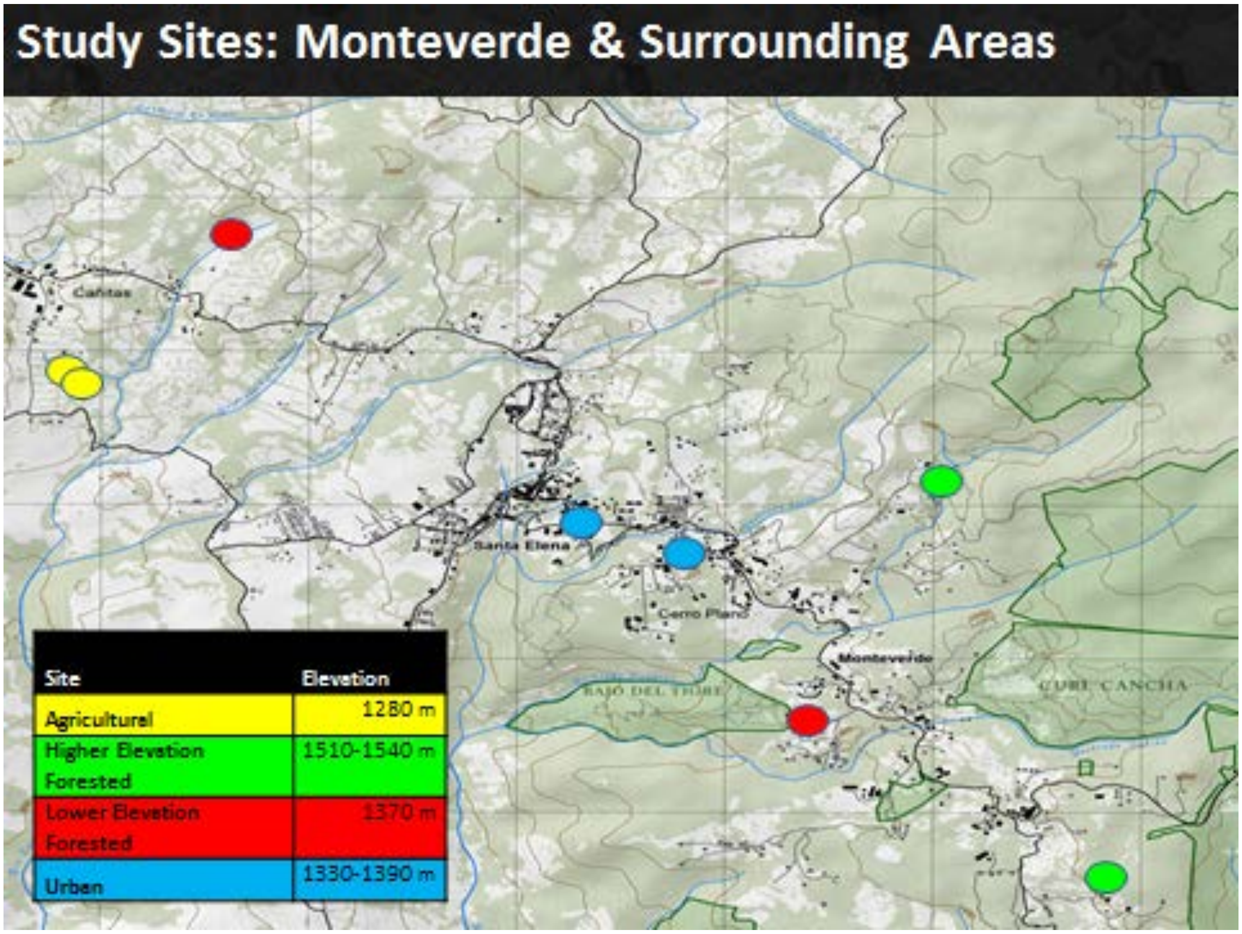


**Figure 1. Greater Monteverde Region: Study Sites are from Canitas (yellow), La Cruz (red), Santa Elena (blue), Cerro Plano (blue), Bajo del Tigre (red), and Monteverde (green).**

Procedure- I used an "Echo Meter Touch" (EMT) recorder ( www.WildlifeAcoustics.com) with the Wildlife acoustic Echo Meter Touch app connected to an iPad to record calls made by insectivorous bats. The recording range of the EMT's microphone can receive input from 8 kHz to 125 kHz. I set the preferences to record at a medium level of sensitivity because preliminary observation on the most sensitive setting recorded too much noise interference that compromised quality of the bat recordings. Sampling took place from 6 pm to 10 pm. I placed the recorder on top of a 3 meter-tall aluminum pole secured inside a rain cover. Recording equipment was placed to avoid as much interference from movement of trees from the wind. Recordings were analyzed using Analook (AnalookW, 2015) and bat calls were manually identified to species by differences in frequency range and shape (See Appendix B). Prior to identifying the bat calls, the .wav files from the EMT were converted into zero-crossing files using Kaleidoscope software. Calls were identified by comparing them to a reference library provided by Richard Laval from previous recordings in the Monteverde region (R. Laval, unpub. data).

Analysis- I calculated the foraging activity of each of the 4 pairs of sites by using Shannon's Entropy Index equation. Each individual bat call was used to represent the relative foraging activity of that specific species; therefore, the equation represents Shannon's Bat Activity Index. I used a modified t-test to test for a difference between two diversity indices between each location (Zar, 1999).

Species richness was calculated by adding up the total species detected during the two days of sampling between the four localities. I performed a chi-squared test to determine statistical differences between the species richness of the four localities. The overall bat activity between the four localities was compared by adding the total amount of calls and the total duration of all bat calls.

**RESULTS**

I identified a total of 11 species within the 8 nights of sampling. Table 1 shows species that were present at each site. The agricultural sites at Life Monteverde had all 11 species present, while the other three localities ranged from 4 and 5 species (See Appendix C). Only a total of 208 calls out of 3,122 recordings were able to be identified into bat species using Analook. The majority of the calls had recorded insects, or other ultrasonic noise.

**Table 1. Species bio-acoustically identified. 11 species were detected in the 8-day sampling period. All species were detected in the agricultural sites, and no unique species were found in the other three pairs of sites.**

| Species | Agricultural (1280 m) | Lower Forest (1370 m) | Urban (1330-1390 m) | Higher Forest (1510-1540) |
|---|---|---|---|---|
| *Eptesicus brasiliensis* | X | X | X | X |
| *Eptesicus fuscus* | X | | | |
| *Eumops auripendulus* | X | X | X | |
| *Lasiurus ega* | X | | | |
| *Molossus mollosus* | X | X | X | |
| *Molossus sinaloae* | X | | | |
| *Myotis nigricans* | X | X | X | X |
| *Myotis keasyi pilosatibialis* | X | X | | X |
| *Myotis riparius* | X | | | X |
| *Pteronatus dayvi* | X | | | |
| *Tadarida brasiliensis* | X | | X | |

**Table 2. Bat Activity was measured by adding the total amount of calls and total duration of the calls among localities.**

| Site | #of calls | Total Duration (sec) |
|---|---|---|
| Agricultural | 101 | 440 |
| High Elevation Forested | 73 | 236 |
| Lower Elevation Forested | 19 | 94 |
| Urban | 15 | 75 |

While the agricultural locality had a richness over twice as great then the other sites, there was no significant difference in richness between the four localities ($p>0.10$, $\chi^2=4.92$, df=3). The number of bat calls are positively correlated with the total duration of time spent calling which was assumed to be foraging (see table 2). The agricultural site had the most number of calls at 101and total time spent foraging at 440 seconds. The locality with the lowest activity was the urban locality with number of calls at15 and total time spent foraging at 75 seconds. The lower elevation forest locality was similar to the urban locality, and had the two lowest bat activity levels. The high elevation forest fell between the middle of the highest and the two lowest localities in terms of bat activity.

The modified t-test for difference between two diversity indices resulted in a significant difference of H' between all localities ($p<0.01$), except between the low elevation forest and the urban locality ($P>0.10$). The agricultural locality had the highest Shannon's bat activity index with H'=0.89. The lower elevation forest had the second highest with H'=0.67, followed by the urban site with H'=0.52.The locality with the lowest bat activity index was the higher elevation locality with H'=0.20.

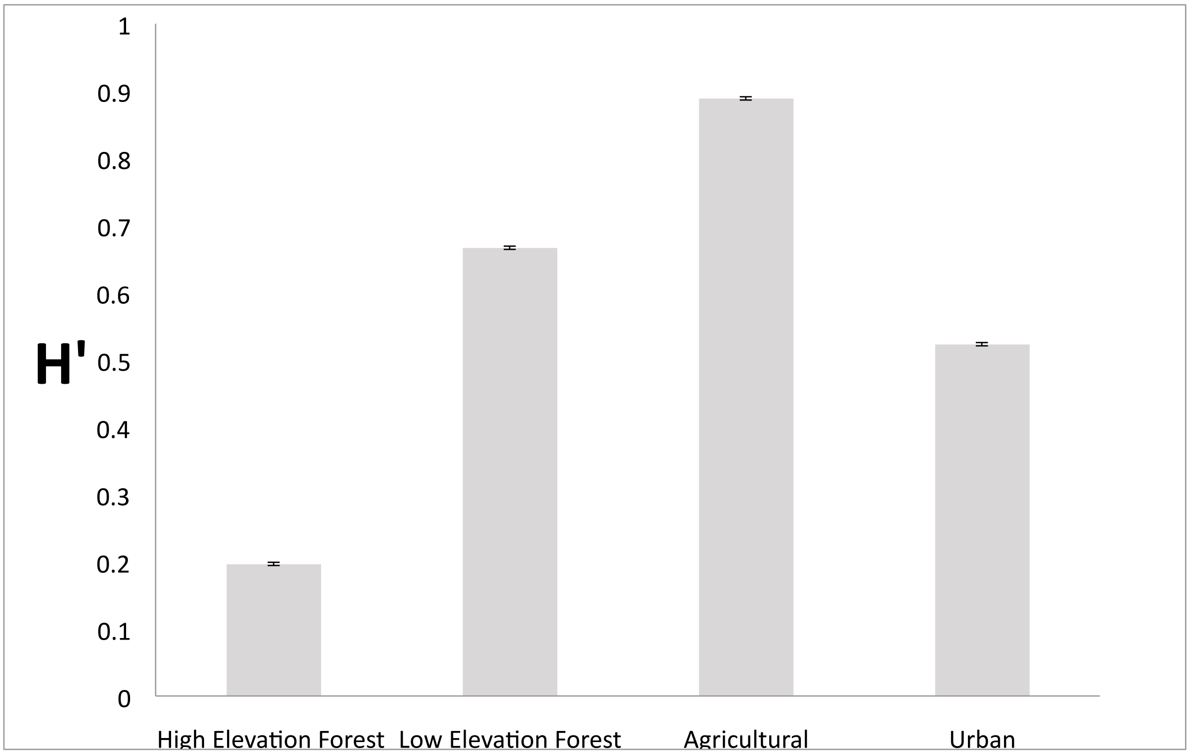


**Figure 2. H' Bat activity index. Bat activity was calculated by using the Shannon's Entropy Index and compared among localities. The error bars represent the variance of H'.**

## DISCUSSION

*Site Analysis*- The agricultural locality had a substantially higher level of foraging activity than the rest of the other localities. Although the two sites I sampled were very open and exposed, the farmers maintain densely forested fragments as windbreaks for their crops. This creates open foraging area with closely adjacent forest that can serve as predation shelter, alternative foraging habitat and potential roosting sites. Many species of aerial insectivorous bats have been observed to prefer forest edge habitat for foraging (Jantzen 2013). Although recording equipment was always placed in areas that were close to forest edge, the sizes and state of the adjacent forests differed among all sites, as did the relative canopy openness in which the recorder was placed. Sampling at the agricultural locality took place during a waxing crescent moon, with no substantial wind or rain interference which all could have contributed to the higher amount of foraging activity. Studies show that some bat activity is higher during darker lunar phases (Lang, 2006, Reith, 1982and Morrison, 1978)

The lower elevation forest consisted of two sites; one in Bajo del Tigre and one in La Cruz. The forest at La Cruz is primary growth forest and is adjacent to large areas of land cleared for pasture. The forest at Bajo del Tigre is connected to a large forested area that connects to forest at lower elevations. Bat diversity is generally higher at lower elevations, depending on habitat (Laval and Rodriguez, 2002). This could have contributed to the relatively higher H' value compared to the higher forested locality. Since the recorder was placed inside a canopy, the waxing gibbous moon was not considered a significant variable during these nights. Rain was a significant factor for one day of sampling which could have affected the amount of activity recorded.

The rain, moonlight, and wind were significant factors in the two other localities: high elevation forested and urban sites. Sampling during the site at Bull Pen (see Fig 1) which represented higher elevation forest was especially windy (15-35 km/h) and had a full moon, which are significant factors that can reduce bat activity (Ciechanowski, 2007). However, the bat activity at these two sites might have been influenced most by the elevational difference, as previously mentioned, bat activity reduces with greater elevation (LaVal and Rodriguez, 2002). There were no unique species in any of the sites other than the agricultural sites. The urban site experienced rain and high insect interference, this affected recording because the EMT is only accurate for a single individual at a time. The only two localities in which foraging activity were not significantly different from one another were the low elevation forest and the urban. The elevations of the two localities overlap, however the landscape differs greatly. The closed canopy with no artificial lights compared to the exposed sky with city lights is a drastic comparison. Species composition of these two localities only varied by one species (4 of the 5 species were the same- See Table 1). Therefore, I cannot conclude that urban development affects the species composition or foraging activity of insectivorous bats.

Elevation seems to be the largest component affecting insectivorous bat species composition and bat foraging activity. Developed land for agriculture seemed to be preferred habitat for foraging, while higher elevation forest was the least preferred. The two areas that differed in landscape composition and human development (urban and forested) did not differ significantly both in species richness and bat foraging activity. Therefore the bat community in Monteverde cannot be said to be negatively impacted by human development. In contrast, developed land such as agriculture or pasture could have increased preferred foraging habitats for some insectivorous bats.

*Species Composition*- Only two species were found throughout all four localities: *Eptesicus brasiliensis* and *Myotis nigricans*, both belonging to the family Vespertilionidae. These are both common bats in Costa Rica and are known to roost in buildings (LaVal and Rodriguez, 2002). Another bat that thrives in in developed areas is *Tadarida brasiliensis*, this study only detected this species in the areas that were developed. *T. brasiliensis* is known to roost in man-made structures in large colonies of thousands. This could be an explanation for why they are not perturbed by human disturbances; their colonies are most likely loud and have a large amount of social activity. In contrast, *Myotis keasyi pilosatibialis* were found in all sites except the urban area. One study observed that *M. k. pilosatibialis* avoided artificial lights (Frank 2015). One possible explanation for this is that *M. k. pilosatibialis* is a low flyer, thus its food-source may not be found at street lights since larger insects tend to be more attracted artificial lights (Langevelde et al., 2011).

Species that were found on all three sites, except the higher elevation forest included *Eumops auripendulu,* and *Molossus molossus.* This suggests that their foraging in most restricted by their home range of lower elevation. These species were not historically present in the Monteverde area, but has expanded its home range due to climate change (Jansen, 1983 and LaVal, 2004). Species that were only found in the agricultural area included: *Pteronotus dayvi, Eptesicus fuscus, Lasiurus ega,* and *Molossus sinaloae.* These species represent three different families: Mormoopidae, Vespertilionidae, and Molossidae. Some of these species can be found foraging over water (LaVal and Rodriguez, 2002). The agricultural site at Life Monteverde has a stream less than 100 meters from the sampling location, therefore this could be a possible explanation as to why this site has the most species richness. Lastly, Myotis riparius was also found in the agricultural site, but also in the higher elevation forest, its natural history suggests that is commonly found in primary forest which could explain why it was seen at the higher elevation site (LaVal and Rodriguez, 2002).

*Further studies*- I suggest historical records should be analyzed and expanded to include fruit-eating and nectar-feeding bats. Extensive studies in this general area have been conducted by Richard K. LaVal and Eric Dinnerstein for the past 30 years. This information could be valuable to determine how bat communities have changed over time and with increasing human development. Because this study is exclusive to aerial insectivorous bats, I was unable to determine how other bats with different diets are affected by development. This study was conducted during an El Nino year, therefore, I would also suggest comparing similar data to different years and seasons.

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# Appendices

Appendix A

| Site | elevation (m) | locality representation |
|---|---|---|
| Life Monteverde- Coffee Plot | 1280.487805 | Agricultural |
| Life Monteverde- Organic Garden | 1280.487805 | Agricultural |
| Cerro Plano- Banco de Costa Rica | 1390.243902 | Urban |
| Cerro Plano- La Taverna | 1329.268293 | Urban |
| La Cruz- Evelio Finca | 1371.95122 | Low elevation forest |
| Bajo del Tigre- Frank Joyce Residence | 1371.95122 | Low elevation forest |
| Monteverde cloud forest- La Estacion Biologica | 1539.634146 | High elevation forest |
| Monteverse cloud forest-Bull Pen Finca | 1509.146341 | High elevation forest |

Appendix B

| Species | Range of Echolocation frequency (kHz) | Description |
|---|---|---|
| *Eptesicus brasiliensis* | 25-35 | frequency modulated call, bottom of call most commonly crossing through 35 kHz |
| *Eptesicus fuscus* | 25-35 | similar to *E. brasiliensis*, bottom of call most commonly crossing below 30 kHz |
| *Eumops auripendulus* | 15-20 | constant frequency, only *Eumop* in area, |
| *Lasiurus ega* | 30-35 | Frequency modulated, pattern at bottom of call curves back up, resembles lower case h |
| *Molossus mollosus* | 25-35 | constant frequency, bottom of call moslty below 35 kHz |
| *Molossus sinaloae* | 30-40 | constant frequency, can be confused with M. molossus, however not as common and calls are mostly above 35 kHz |
| *Myotis nigricans* | 50-55 | conspicuous L shaped pattern, often found below 55kHz |
| *Myotis keasyi pilosatibialis* | 63-67 | conspicuous L shaped patter, moslty crossing at 65kHz |
| *Myotis riparius* | 55-60 | can be confused with *M. nigricans* but call is moslty above 55 kHz |
| *Pteronatus dayvi* | 50-65 | pattern varies, often has a 7 shaped call or where call is contant at 55 or 65 kHz then drops straight down |
| *Tadarida brasiliensis* | 25-35 | usually crosses 30kHz, however can jump from 25 khz to 40 khz |

Appendix C

| Site | Species Richness |
|---|---|
| Agricultural | 11 |
| High Elevation Forested | 4 |
| Lower Elevation Forested | 5 |
| Urban | 5 |

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