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Acoustics records of three *Pteronotus* species from Vichada, Colombia

Registros acústicos de tres especies de *Pteronotus* en Vichada, Colombia

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Insectivorous bats of the genus *Pteronotus* are considered rare or uncommon because they are difficult to capture with traditional methods (*i.e.*, mist nets and harp traps). However, these bats have a distinct echolocation call design that enables their detection and recognition acoustically. In this note, we report the presence of 3 species of bats of the *Pteronotus* genus based on acoustic records from the department of Vichada in Colombia and we present a brief characterization of the echolocation calls for each species. We conducted passive acoustic monitoring in 3 localities and analyzed echolocation calls of sequences. Additionally, we searched for bat capture records in biological collections and scientific articles to find out the current distribution of the *Pteronotus* genus in Colombia. We recorded 3 species of bats of the *Pteronotus* genus: *P. personatus*, *P. gymnonotus*, and *P.* cf. *rubiginosus*. As for the search of records in biological collections and articles, we found that 8 out of 59 records of *Pteronotus* species in Colombia were from Vichada department. This work provides evidence that acoustic surveys for bats efficiently register elusive and difficult-to-capture insectivorous species, such as those of the genus *Pteronotus*.

Key words: Acoustics; echolocation; insectivorous bats; mormoopids; Orinoquia.

Los murciélagos insectívoros del género *Pteronotus* son considerados raros o poco comunes por su difícil captura con métodos tradicionales (*i.e.*, redes de niebla y trampas arpa). Sin embargo, estos murciélagos emiten señales de ecolocalización distinguibles que facilitan su detección y reconocimiento mediante métodos acústicos. En esta nota, reportamos la presencia de 3 especies de murciélagos del género *Pteronotus* a partir de registros acústicos en el departamento de Vichada, en Colombia y presentamos una breve caracterización de las señales de ecolocalización para cada una de las especies. Realizamos un monitoreo acústico pasivo en 3 localidades y analizamos las secuencias de los pulsos de ecolocalización. Adicionalmente, realizamos una búsqueda de registros de capturas en colecciones biológicas y artículos científicos para conocer la distribución actual de *Pteronotus* en Colombia. Registramos acústicamente 3 especies de murciélagos del género *Pteronotus: P. personatus*, *P. gymnonotus* y *P.* cf. *rubiginosus*. En cuanto a la búsqueda de registros en colecciones y artículos encontramos 59 registros a partir de capturas de especies de *Pteronotus* en Colombia, de los cuales 8 pertenecen al departamento de Vichada. Este trabajo aporta evidencia a la noción de que los estudios con el uso de métodos acústicos en murciélagos son eficientes para el registro de especies insectívoras difíciles de capturar, como las del género *Pteronotus*.

Palabras clave: Acústica; ecolocalización; mormoópidos; murciélagos insectívoros; Orinoquia.

Bats of the genus *Pteronotus* Gray, 1838 are characterized for having a slow and maneuverable flight, adapted for hunting insects in cluttered spaces, like forest interiors and edges (Bateman and Vaughan 1974). *Pteronotus* species have highly distinct echolocation calls from other species of insectivorous bats: calls are multi-harmonics with peak frequencies in the second harmonic, employing different combinations of constant frequency (CF) and modulated frequency (FM) elements in each echolocation call (O'Farrell and Miller 1997). In general, bats of the *Pteronotus* genus broadcast calls with a main FM component coupled with CF components at the beginning and the end of the call, except for *Pteronotus* cf. *rubiginosus* Wagner, 1843 which emits pulses composed by a short ascendent FM sweep (~ 5 ms), followed by a long CF component (~ 20 ms) and finalize with another short descendent FM sweep (~ 5 ms; Mancina *et al.* 2012). Moreover, *P.* cf. *rubiginosus* and *Pteronotus personatus* Wagner, 1843 have adapted a sophisticated hearing system to compensate for the Doppler effect, which makes them able to shift down the emitted narrowband frequencies in the CF structure of their echolocation calls as they reach top flight speed, ensuring that returning echoes remain within the best auditive sensitivity range of the bat (Smotherman and Guillén-Servent 2008; Schnitzler and Denzinger 2011).

The genus *Pteronotus* is restricted to the Neotropics with distribution from western México, Central America, and the Antilles, to northeastern Brazil on the east portion and Perú on the western part of South America (Gardner 2007; Pavan and Marroig 2016). Currently, 5 species are distributed in Colombia: *Pteronotus davyi* Gray, 1838*, Pteronotus gymnonotus* Natterer, 1843*, Pteronotus fuscus* J. A. Allen, 1911, *P. rubiginosus* and *P. personatus,* and all have been widely observed in the departments of Antioquia, Bolívar, Cauca, Cesar, Cundinamarca, La Guajira, Huila, Magdalena, Sucre, and Tolima under 1,200 m (Alberico *et al.* 2000; Solari *et al.* 2013; Ramírez-Chaves *et al.* 2021). For the department of Vichada, there is only one published record at the Santa Teresita locality for *P. personatus* (Montes *et al.* 2012). However, other non-published records of biological collections hint at a wider distribution of the genus in the eastern regions of Colombia.

Currently, acoustical tools have become more relevant for monitoring the insectivorous bat guild, mainly due to the difficulty of capturing these bats with traditional methods (*i.e.*, mist nets and harp tramps), like species of the *Pteronotus* genus (MacSwiney *et al.* 2008). Since the species of *Pteronotus* have a distinct echolocation call, it is possible to identify them in acoustic surveys. In this note, we report the presence of *P. personatus*, *P. gymnonotus,* and *P.* cf. *rubiginosus* with acoustic methods in the Vichada department in Colombia and we present a brief characterization of the echolocation calls for each one of the 3 species, thus providing more evidence supporting the utility of using acoustic records for the completeness of wildlife inventories, specifically for elusive species difficult to register.

We conducted an acoustic survey in 2 locations, "La Reserva Forestal La Pedregoza" (RFLP) in February 2018 and in the "Caño Negro" farm in November 2020. The 2 study areas are characterized by forest plantations, riparian forests, and natural savannas in the circumscription of Puerto Carreño, Vichada (Figure 1). In the RFLP, we installed an SM4 FS ultrasonic detector with an SMM - U1 microphone (Wildlife Acoustics® Maynard, MA, USA) for 5 nights in pine (1 night) and acacia crops (2 night), natural savannas (1 night) and gallery forests (1 night), from 18:00 hr to 6:00 hr. At Caño Negro farm, we conducted active acoustic monitoring with an Echo Meter Touch 2 Pro ultrasonic detector

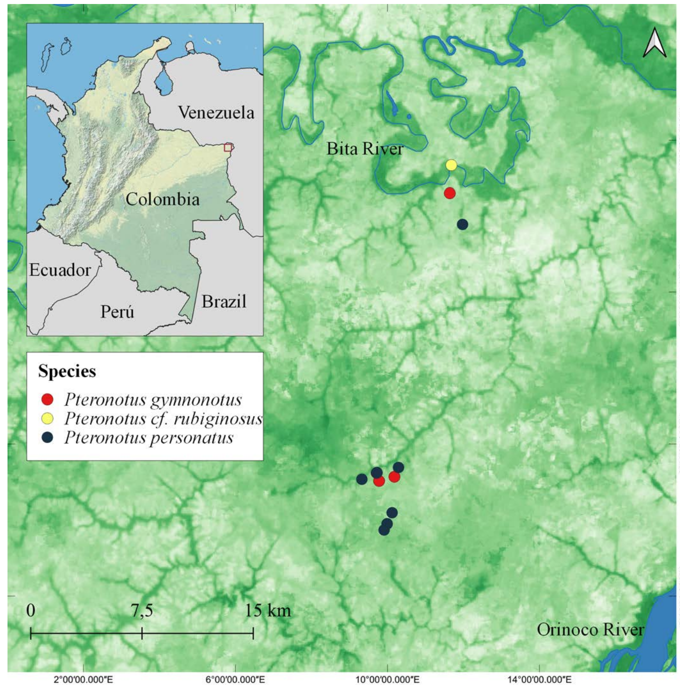

Figure 1. Occurrences of *Pteronotus* cf. *rubiginosus*, *Pteronotus gymnonotus*, and *Pteronotus personatus* in the department of Vichada, Colombia. The red dots correspond to acoustic records of *P. gymnonotus*, the yellow dots of *P.* cf. *rubiginosus*, and the blue dots to *P. personatus*.

for 3 nights in different land cover uses between 18:00 hr - 22:00 hr: forest plantations (acacia crops and pine crops), riparian forests, and natural savannas. We performed 5-min recordings in 30 points per land use cover spaced every 300 m. In both locations, we configured the detectors with a sampling rate of 384 kHz and a gain of 12 dB. We analyzed 337 echolocation calls from 46 echolocation sequences with Bat Explorer software, version 2.1 ©Elekon AG (https://www.elekon.ch/). To generate spectrograms, we used a Hamming window with a fast Fourier transformation (FFT) of 512 points and an overlap of 80 %. We measured the second harmonic for all 3 species, as it concentrates most of the energy of each echolocation call, with very few exceptions. We only used the echolocation pulses of each sequence with the best signal-to-noise ratio and measured the pulses in the search and approach phase. In total, we measured 8 acoustic parameters (Appendix 1), following the recommendations proposed by Martínez-Medina *et al.* (2021a)**.** The 5 recordings corresponding to the 3 species presented in this paper have been deposited in the Environmental Sound Collection "Mauricio Álvarez Rebolledo" of the Alexander von Humboldt Institute under the following numbers IAvH - CSA 18829 to IAvH - CSA 18833.

To know the current distribution of *Pteronotus* in Colombia, we carried out an exhaustive search of public access databases such as the Biodiversity Information System of Colombia (SIB Colombia 2021) and the Global Biodiversity Information Facility (GBIF.org 2021), in biological collection records, and scientific literature (Cuervo-Díaz *et al.* 1986; Alberico *et al.* 2000; Montes *et al.* 2012; Solari *et al.* 2013; Chacón-Pacheco *et al.* 2018). All records from these sources were obtained through captures in mist nets. Finally, for the scientific literature search, we used the keywords "*Pteronotus* AND Colombia" excluding the records that were not georeferenced.

We obtained a total of 44 sound files with calls of *Pteronotus* distributed by each species as follows: *P. personatus* was recorded in 16 sound files along the riparian forest, 9 in acacia crops, 8 in pine woods, and 3 in savannas, *P. gymnonotus* in 3 recordings of acacia crops and *P.* cf. *rubiginosus* in 5 recordings of riparian forest. Because several recordings did not have a good signal-to-noise ratio, the number of measured sequences did not correspond to the number of recording points (Appendix 1).

The call structure of *P. personatus* and *P. gymnonotus* (Figure 2a, 2b) consisted of a descending FM sweep framed between a short initial CF element and a short terminal descending quasiconstant frequency (QCF) sweep (CF/FMd/QCFd), similar to those reported by O'Farrell and Miller (1997), MacSwiney *et al.* (2008), Briones-Salas *et al.* (2013), Orozco-Lugo *et al.* (2013), Zamora-Gutierrez *et al.* (2016) and Arias-Aguilar *et al.* (2018; Appendix 1). In addition, we recognized variations in some of the temporal and spectral parameters of echolocation calls from reference acoustic records of other neotropical countries for these species.

The average call duration of *P. personatus* was higher than the average of O'Farrell and Miller (1997), Orozco-Lugo *et al.* (2013), and Zamora-Gutierrez *et al.* (2016). However, within the reported variability range of all the references mentioned above. On the other hand, the call duration values of Briones-Salas *et al.* (2013) are lower and do not overlap with any value in the duration range reported in our study. Likewise, the average Maximum Frequency (MaxF) and the Minimum Frequency (MinF) of our study were lower than the average of the references mentioned before but, again, with overlapping bandwidths, being those of O'Farrell and Miller (1997) and MacSwiney *et al.* (2008) closer to our observations, and those of Briones-Salas *et al.* (2013) and Zamora-Gutierrez *et al.* (2016) broader for approximately 3 and 7 kHz, respectively. Concerning the inter-pulse interval found in our study, it is consistent with the range reported by MacSwiney *et al.* (2008) and Orozco-Lugo *et al.* (2013) but much higher than that reported by O'Farrell and Miller (1997; Appendix 1).

For *P. gymnonotus*, the average call duration was higher than the references of Zamora-Gutierrez *et al.* (2016), MacSwiney *et al.* (2008), and Arias-Aguilar *et al.* (2018), but overlapping in the range of the highest values, except for the last reference which fell below the 6 ms of duration. Also, the MaxF and MinF observed in this work were higher than those values reported by MacSwiney *et al.* (2008) and Zamora-Gutierrez *et al.* (2016). Again, the exception was the MinF reported by Arias-Aguilar *et al.* (2018), which was marginally higher than ours. Furthermore, the bandwidths of all references were quite similar (14 - 17 kHz for all the references, including the present work), containing overlapping frequencies. Finally, our average value of the inter-pulse interval was within the range of variation reported by Arias-Aguilar *et al.* 2018 (Appendix 1).

In addition, the call structure for *P.* cf. *rubiginosus* (Figure 2a) consisted of a long-duration CF segment framed between two short ascending and descending FM sweeps (FMa/CF/FMd) and are similar to echolocation signal structures reported for the species complex of *P. parnellii* by O'Farrell and Miller (1997), Macías *et al.* (2006), MacSwiney *et al.* (2008), Pio *et al.* (2010), Briones-Salas *et al.* (2013), Zamora-Gutierrez *et al.* (2016) and Arias-Aguilar *et al.* (2018). The call duration average reported in the present work was higher than those values reported by Macías *et al.* (2006), Pio *et al.* (2010), Briones-Salas *et al.* (2013), Zamora-Gutierrez *et al.* (2016), and Arias-Aguilar *et al.* (2018) and overlapped with those reported by MacSwiney *et al.* (2008) and Orozco-Lugo *et al.* (2013). The MaxF values of our study were lower than those reported in all the references mentioned above, except for those reported by Arias-Aguilar *et al.* (2018), which were lower than ours. The MinF values showed the same pattern of higher frequencies, except for those values reported by Pio *et al.* (2010), Zamora-Gutierrez *et al.* (2016), and Arias-Aguilar *et al.* (2018), which were lower than ours. All the bandwidths of the references, including those reported in this work, overlapped except the one reported by MacSwiney *et al.* (2008), which was the narrowest of the current references and was above the bandwidth reported by us. We reported a higher inter-pulse interval than any of those reported in previous references (Appendix 1).

The search for bat capture records in biological collection and scientific references yielded a total of 59 records of *Pteronotus* species found in Colombia, from which only 8 records belonged to the department of Vichada: 4 records of *P.* cf. *rubiginosus,* 3 records of *P. personatus* and 1 record of *P. gymnonotus* (Appendix 2).

Insectivorous bats inhabiting the understory of forests are adapted to emit short-high frequency FM echolocation calls that render better distance resolution of the objects in their surroundings that are close to each other. Nonetheless, these echolocation calls tend to attenuate also at short distances. Conversely, the bats commonly found in forest edges use these types of FM structures in combination with other call structures such as QCF and CF echolocation calls better suited for long-distance detection, given these concentrate the vast majority of the call energy in a narrow-band of frequencies that travels further in space (Neuweiler 1989; Schnitzler *et al.* 2003).

The echolocation call structures of the acoustic records of *P. personatus* and *P. gymnonotus* found in acacia crops, savannas, riparian forests, and pine crops reported in this study are a good example of the combination of call types adapted by bats using spaces like forest edges to forage for flying insects. These types of habitats impose conditions found in forest interiors on one side, along with open spaces on the other side. This combination of call structures

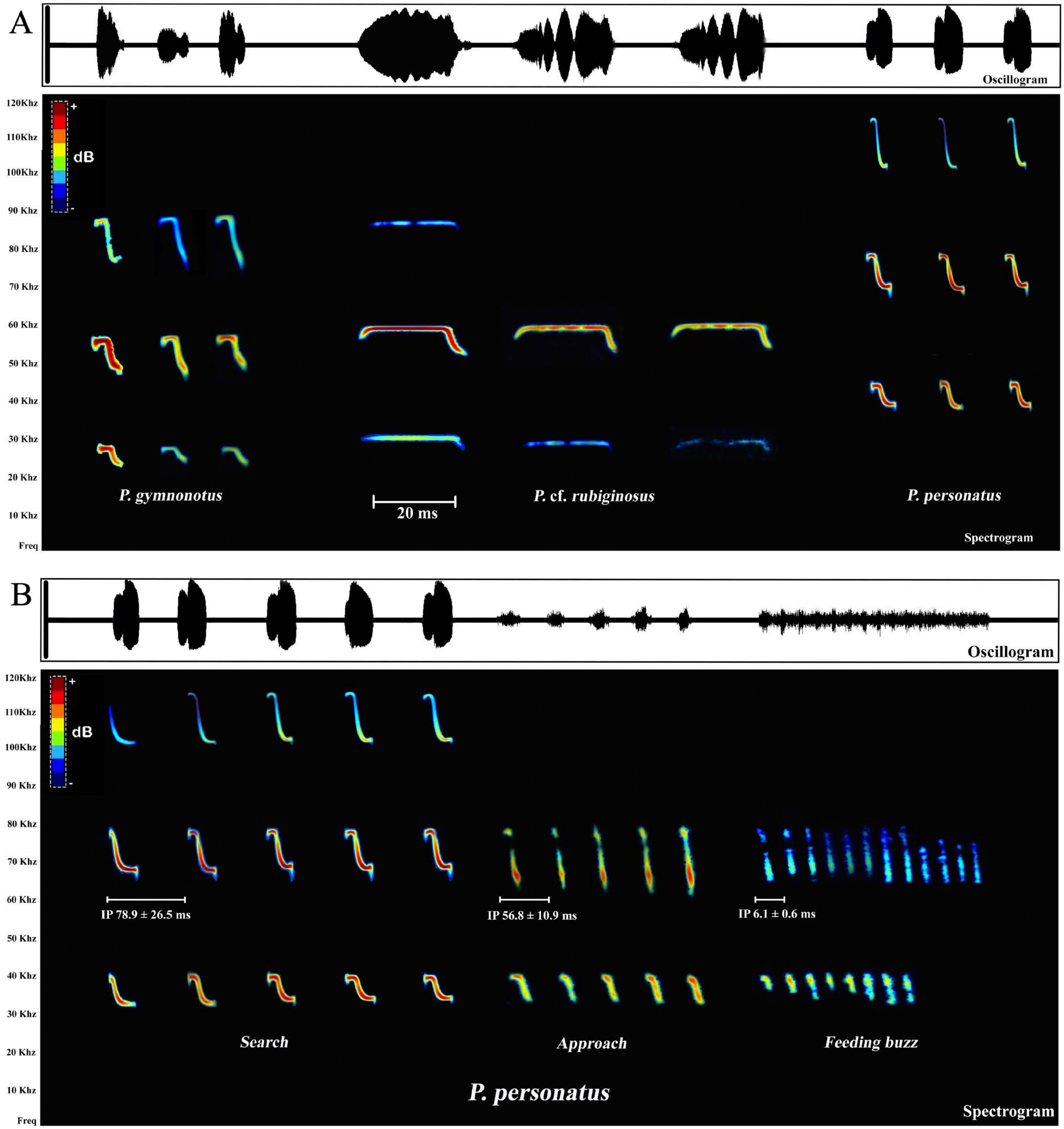

Figure 2. Spectrograms and oscillograms of echolocation signals emitted by mormoopid species in Vichada, Colombia. A) Echolocation calls emitted during search flight by *Pteronotus gymnonotus, Pteronotus* cf. *rubiginosus*, and *Pteronotus personatus*. B) Representation of echolocation signals emitted by *P. personatus* during the search phase, approach phase, and feeding buzz. Pulse intervals are not scaled.

can also explain the observations of *P. personatus* using water streams and rivers associated to dense vegetation, representing a combination of cluttered and less cluttered spaces (Kober and Schnitzler 1990; O'Farrell and Miller 1997; Guillén-Servent 2005; de la Torre and Medellín 2010; Pavan and Tavares 2020). The echolocation call structure observed in the recordings of *P.* cf. *rubiginosus* found in the forest is also consistent with its capability of flying through cluttered sites with dense vegetation in search of fluttering insects. This structure consists of high frequency-long narrowband CF calls that are compensated for the Doppler shifts in the echo frequency, allowing bats with the recognition of amplitude and frequency micro modulations in the returning echoes, typically induced by moving prey (Kober and Schnitzler 1990; Von der Emde and Schnitzler 1990; Kalko *et al.* 2008; de Oliveira *et al.* 2015).

Recently, Clare *et al.* (2013) proposed a change in the taxonomic level of continental populations of the subspecies of *P. parnelli* complex, *P. parnelli fuscus*, and *P. parnelli rubiginosus* would now be upgraded to species level. Hence, *P. parnelli* becomes an exclusive species of insular distribution and the Colombian populations of the new *P. fuscus* would be distributed on the Caribbean coast, while the *P. rubiginosus* populations would be distributed in the eastern part of Colombia (Pavan and Marroig 2016). Therefore, the sonotype (*i.e.*, the group of sounds with the same characteristics and that are assumed to correspond to the same species; Bader *et al.* 2015) we recorded in this study was determined by the proposed geographic distribution as *P.* cf. *rubiginosus*. Something similar happens with the *P. personatu*s complex, so we use the references of *P. personatus* from México for comparison, currently known as *P. psilotis* Dobson, 1878 (Zárate-Martínez *et al.* 2018; Arias-Aguilar and Ramos-Pereira 2022).

It is noteworthy that the recent "Clave de Identificación de los Murciélagos Neotropicales" published by Díaz *et al.* (2021) proposed a discrimination between species of *P. rubiginosus* and *P. fuscus,* based on echolocation call of the characteristic frequency. Nevertheless, there's not sufficient acoustic evidence in Colombia supporting this discrimination. Since the *P. parnellii* complex exhibits Doppler shift compensation (Smotherman and Guillén-Servent 2008; Schnitzler and Denzinger 2011), discrimination based on small differences in peak frequencies (~ 3 kHz) of the CF component of its echolocation calls are not straightforward. To fulfill proper discrimination between species, there must be reference recordings of identified individuals obtained under controlled conditions regarding flight spaces, flight speed, body size, sex, and development condition, given that these factors can alter the frequency in the emission of echolocation calls for most bats (Jones 1997; Jacobs *et al.* 2007; Jones and Holderied 2007).

Through the search of biological collection records and scientific references, we found that the Vichada department is one of the places with the fewest records of mammals we found in the country, and remarkably the only record of *P. gymnonotus* in this department was in 1967, that is, approximately 50 years ago (GBIF.org. 2021). So far, the records of *Pteronotus* species that have been published for the department of Vichada (Montes *et al.* 2012; Páez-Vásquez *et al.* 2020) or the Orinoco River basin (Ferrer-Pérez *et al.* 2009a) are based on captures with mist nets or specimens from scientific collections. However, using acoustic methods, we recorded 3 species of *Pteronotus* for the department of Vichada: *P.* cf. *rubiginosus*, *P. gymnonotus*, and *P. personatus*.

Studies of bats using acoustic methodologies have shown that they are efficient in recording rare insectivorous bat species, such as those of the family Mormoopidae (MacSwiney *et al.* 2008). Using acoustic tools can increase the richness of Chiroptera sets by up to 40 % (MacSwiney *et al.* 2008). Therefore, the complementary use of these methodologies is necessary to register species of insectivorous bats that are not commonly obtained by traditional methodologies. In Colombia, the studies on bat acoustics are still relatively new (Martínez-Medina *et al.* 2021b), and this field of knowledge has been increasing in recent years. Bat echolocation call descriptions of Colombian species are key for the conservation of their communities since these characterizations contribute to the identification capacity of bat monitoring programs, aiming to assess the impacts of different human activities on the spatial-temporal patterns of bat activity (Walters *et al.* 2013). Furthermore, knowledge of the bat reference acoustic parameters is fundamental to understanding the intra-and-interspecific variations of the bats' ultrasonic vocalizations, improving the sound collection performed in the country.

The present work is one of the first contributions to the acoustic ecology of the Mormoopidae family in Colombia, identifying acoustic variations for the 3 species of *Pteronotus* to what has been reported up to date for Central and South America. Although these variations could be the product of inter and intraspecific factors such as sex, age, body condition, reproductive stage (Jones 1997; Jacobs *et al.* 2007; Jones and Holderied 2007), or a consequence of environmental factors like the increased absorption of the high frequencies in echolocation calls recorded in humid environments, the amount of vegetative clutter in foraging spaces and noisy conditions (Lawrence and Simmons 1982; Arlettaz *et al.* 2001; Kalko *et al.* 2008; Tressler and Smotherman 2009). We urge the scientific community to record reference calls accompanied by the collection of voucher specimens as the only way to ensure that each acoustic record will provide full information for species discrimination as would be the case of the *P. parnellii* complex, given the taxonomic transitions these species have been through in recent years.

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Literature cited

Alberico, M., *et al.* 2000. Mamíferos (Synapsida:Theria) de Colombia. Biota Colombiana 1:43-75.

Arias-Aguilar, A., *et al.* 2018. Who's calling? Acoustic identification of Brazilian bats. Mammal Research 63.

Arias-Aguilar, A., and M. J. Ramos-Pereira. 2022. Acoustic clue: bringing echolocation call data into the distribution dilemma of *Pteronotus* (Chiroptera: Mormoopidae) complexes in Central America. Biological Journal of the Linnean Society 135:586–598.

Arlettaz, R., G. Jones, and P. A. Racey. 2001. Effect of acoustic clutter on prey detection by bats. Nature 414:742–745.

Bader, E., *et al*. 2015. Mobility explains the response of aerial insectivorous bats to anthropogenic habitat change in the Neotropics. Biological Conservation 186:97–106.

Bateman, G. C., and T. A. Vaughan. 1974. Nightly Activities of Mormoopid Bats. Journal of Mammalogy 55:45-65.

Bejarano-Bonilla, D. A., A. Yate-Rivas, and M. H. Bernal-Bautista. 2007. Diversidad y distribución de la fauna quiroptera en un transecto altitudinal en el departamento del Tolima, Colombia. Caldasia 29:297-308.

Briones-Salas, M., M. Peralta-Pérez, and M. García. 2013. Acoustic characterization of new species of bats for the State of Oaxaca, Mexico. Therya 4:15-32.

Chacón-Pacheco, J., J. Ballesteros-Correa, and J. Racero-Casarrubia. 2018. Nuevos registros de *Pteronotus parnellii* (Chiroptera, Mormoopidae) en el departamento de Córdoba, Colombia. Boletín Científico Centro de Museos Museo de Historia Natural 22:121–127.

Clare, E. L., *et al*. 2013. Diversification and reproductive isolation: cryptic species in the only New World high-duty cycle bat, *Pteronotus parnellii*. BMC Evolutionary Biology 13:26.

Cuervo-Díaz, A., J. Hernández, and A. Cadena. 1986. Lista actualizada de los mamíferos de Colombia: Anotaciones sobre su distribución. Caldasia 15:71-75.

de Oliveira, L.Q., *et al*. 2015. Activity of the insectivorous bat *Pteronotus parnellii* relative to insect resources and vegetation structure. Journal of Mammalogy 96:1036-1044.

de la Torre, J.A., and R. A. Medellín. 2010. *Pteronotus personatus.* Mammalian Species 42:244–250.

Díaz, M., *et al*. 2021. Clave de identificación de los murciélagos neotropicales. Publicación Especial N°4 Programa de Conservación de los Murciélagos de Argentina. Tucumán, Argentina.

Ferrer-Pérez, A., *et al*. 2009a. Lista de los mamíferos de la cuenca del río Orinoco. Biota Colombiana 10:179-207.

Ferrer-Pérez, A., M. Beltrán, and C. A. Lasso. 2009b. Mamíferos de la estrella fluvial de Inírida: ríos Inírida, Guaviare, Atabapo y Orinoco (Colombia). Biota Colombiana 10:209-218.

Gardner, A. L. 2007. Mammals of South America. The University of Chicago Press. Chicago, U.S.A.

GBIF.org. 2021. Occurrence Download. https://www.gbif.org/occurrence/download/0233508-200613084148143. Accessed on March 26, 2021.

Guillén-Servent, A. 2005. Diversity of echolocation and foraging behavior of mormoopid bats in an evolutionary context. Bat Research News 46:1801–1817.

Jacobs, D. S., R. M. R. Barclay, and M. H. Walker. 2007. The allometry of echolocation call frequencies of insectivorous bats: Why do some species deviate from the pattern? Oecologia 152:583–594.

Jones, G. 1997. Acoustic Signals and Speciation: The Roles of Natural and Sexual Selection in the Evolution of Cryptic Species. Advances in the Study of Behavior 26:317–354.

Jones, G., and M. W. Holderied. 2007. Bat echolocation calls: adaptation and convergent evolution. Proceedings of the Royal Society B: Biological Sciences 274:905–912.

Kalko, E. K., *et al*. 2008. Flying high-Assessing the use of the aerosphere by bats. Integrative and Comparative Biology 48:60–73.

Kober, R., and H. U. Schnitzler. 1990. Information in sonar echoes of fluttering insects available for echolocating bats. The Journal of the Acoustical Society of America 87:882–896.

Lawrence, B. D., and J. A. Simmons. 1982. Measurements of atmospheric attenuation at ultrasonic frequencies and the significance for echolocation by bats. The Journal of the Acoustical Society of America 71:585–590.

Macías, S., E. C. Mora, and A. García. 2006. Acoustic identification of mormoopid bats: A survey during the evening exodus. Journal of Mammalogy 87:324–330.

MacSwiney, M. C., F. M. Clarke, and P. A. Racey. 2008. What you see is not what you get: The role of ultrasonic detectors in increasing inventory completeness in Neotropical bat assemblages. Journal of Applied Ecology 45:1364–1371.

Mancina, C. A., L. García-Rivera, and B. W. Miller. 2012. Wing morphology, echolocation, and resource partitioning in syntopic Cuban mormoopid bats. Journal of Mammalogy 93:1308–1317.

Martínez-Medina, D., *et al*. 2021a. Estándares para registrar señales de ecolocalización y construir bibliotecas de referencia de murciélagos en Colombia. Biota Colombiana 22:1–17.

Martínez-Medina, D., *et al*. 2021b. Estado, desarrollo y tendencias de los estudios en acústica de la fauna en Colombia. Biota Colombiana 22:7–25.

Montes, G., *et al*. 2012. Nuevos datos sobre la distribución de *Pteronotus personatus* (Wagner, 1843) (Chiroptera: Mormoopidae) en Colombia. Revista Colombiana de Ciencia Animal 4:435–440.

Muñoz-Arango, J. 2001. Los murciélagos de Colombia. Sistemática, Distribución, Descripción, Historia natural y Ecología. Editorial Universidad de Antioquia, Medellín.

Neuweiler, G. 1989. Foraging ecology and audition in echolocating bats. Trends in Ecology and Evolution 4:160–166.

O'Farrell, M., and B. W Miller. 1997. A new examination of echolocation calls of some Neotropical bats (Emballonuridae and Mormoopidae). Journal of Mammalogy 78:954-963.

Orozco-Lugo, L., *et al*. 2013. Descripción de los pulsos de ecolocalización de once especies de murciélagos insectívoros aéreos de una selva baja caducifolia en Morelos, México. Therya 4:33–46.

Páez-Vásquez, M., *et al*. 2020. Murciélagos de la Reserva Natural Bojonawi (Escudo Guayanés), Orinoquia, Vichada, Colombia. Pp. 323-343 *in* VIII Biodiversidad de la Reserva Natural Bojonawi, Vichada, Colombia: río Orinoco y planicie de inundación (Lasso, C., F. Trujillo, and M. Morales-Betancourt, eds.). Serie Editorial Fauna Silvestre Neotropical. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt. Bogotá D. C., Colombia.

Pavan, A. C., and G. Marroig. 2016. Integrating multiple evidences in taxonomy: species diversity and phylogeny of mustached bats (Mormoopidae: *Pteronotus*). Molecular Phylogenetics and Evolution 103:184–198.

Pavan, A. C., and V. C. Tavares. 2020. *Pteronotus gymnonotus*. Mammalian Species 52:40–48.

Pio, D. V., *et al*. 2010. Echolocation calls of the bats of Trinidad, West Indies: Is guild membership reflected in echolocation signal design? Acta Chiropterologica 12:217–229.

Ramírez-Chaves, H. E., *et al*. 2021. Mamíferos de Colombia. v1.12. Sociedad Colombiana de Mastozoología. Dataset/Checklist. https://doi.org/10.15472/kl1whs

Schnitzler, H. U., and A. Denzinger. 2011. Auditory fovea and Doppler shift compensation: adaptations for flutter detection in echolocating bats using CF-FM signals. Journal of Comparative Physiology A 197:541–559.

Schnitzler, H. U., C. F. Moss, and A. Denzinger. 2003. From spatial orientation to food acquisition in echolocating bats. Trends in Ecology and Evolution 18:386–394.

SIB Colombia. 2021. Biodiversidad en Cifras, Sistema de Información sobre Biodiversidad de Colombia 2016:1–5.

Smotherman, M., and A. Guillén-Servent. 2008. Doppler-shift compensation behavior by Wagner's mustached bat, *Pteronotus personatus*. The Journal of the Acoustical Society of America 123:4331–4339.

Solari, S., *et al*. 2013. Riqueza, endemismo y conservación de los mamíferos de Colombia. Mastozoologia Neotropical 20:301–365.

Tressler, J., and M. S. Smotherman. 2009. Context-dependent effects of noise on echolocation pulse characteristics in free-tailed bats. Journal of Comparative Physiology A: Neuroethology, Sensory, Neural, and Behavioral Physiology 195:923–934.

Walters, C. L., *et al*. 2013. Challenges of Using Bioacoustics to Globally Monitor Bats. Pp. 479-499 *in* Bat Evolution, Ecology, and Conservation (Adams, R., and S. Pedersen, eds.). Springer. New York, U.S.A.

Von Der Emde, G., and H. U. Schnitzler. 1990. Classification of insects by echolocating greater horseshoe bats. Journal of Comparative Physiology A 167:423–430.

Zamora-Gutierrez, V., *et al*. 2016. Acoustic identification of Mexican bats based on taxonomic and ecological constraints on call design. Methods in Ecology and Evolution 7:1082–1091.

Zárate-Martínez, D. G., *et al*. 2018. Intraspecific Evolutionary Relationships and Diversification Patterns of the Wagner's Mustached Bat, *Pteronotus personatus* (Chiroptera: Mormoopidae). Acta Chiropterologica 20:51–58.

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Appendix 1

Spectral and temporal parameters of the echolocation calls obtained from the search phase of *Pteronotus personatus, Pteronotus gymnonotus, Pteronotus* cf. *rubiginosus*, and *Pteronotus parnellii* recorded in this study and other Neotropical regions. We also added spectral and temporal parameters of the echolocation calls of the approach phase of *P. personatus* and *P.* cf. *rubiginosus.* Mean ± Standard Deviation (X ± *SD*), ms = milliseconds, kHz = kilohertz, IP = Interpulse Interval, SF = Start frequency, EF = End frequency, PF = Peak frequency, MaxF = Maximum frequency, and MinF = Minimum frequency, n = number echolocation pulses and N= number sequences. [1]Vichada, Colombia. [2]Belize. [3]Yucatan Península, México. [4]Oaxaca, México. [5]México. [6]Morelos, México. [7]Brazil. [8]Cuba. [9]Trinidad.

Species	Phase type	Length [ms] (*X ± SD)*	IP [ms] (*X ± SD*)	SF [kHz] (*X ± SD*)	EF [kHz] (*X ± SD*)	PF [kHz] (*X ± SD*)	MaxF [kHz] (*X ± SD*)	MinF [kHz] (*X ± SD*)	n/N	References
P. personatus	Search	6.8 ± 1.3	78.9 ± 26.5	77.2 ± 2.0	66.2 ± 2.0	68.0 ± 4.0	78.5 ± 2.0	65.3 ± 1.7	132/22	This study[1]
	Approach	6.5 ± 1.5	56.8 ± 10.9	78.4 ± 2.3	66.6 ± 2.0	68.6 ± 3.3	79.4 ± 2.2	65.8 ± 22	117/16	This study[1]
	Search	5.7	48.3				83	68	25	O'Farrell and Miller 1997[2]
	Search	7.1 ± 0.5	53.9 ± 10.0			80.1 ± 1.5	80.9 ± 1.5	74.1 ± 4.2	8	MacSwiney *et al.* 2008[3]
	Search	4.40 ± 0.57					83.72 ± 1.44	66.75 ± 1.61	12	Briones-Salas *et al.* 2013[4]
	Search	5.71 ± 1.18		82.83 ± 2.68	64.12 ± 2.84	70.53 ± 5.25	82.88 ± 2.66	64.12 ± 2.84	10	Zamora et al. 2016[5]
	Search	5.7 ± 0.02	55.1	82.2 ± 0.05	67.6 ± 0.02	81.4 ± 0.05			-	Orozco-Lugo *et al.* 2013[6]
P. gymnonotus	Search	7.5 ± 0.9	68.0 ± 3.5	57.5 ± 3.2	49.8 ± 3.1	57.2 ± 3.9	58.8 ± 3.6	48.5 ± 3.4	34/3	This study[1]
	Search	5.33 ± 0.82		54.99 ± 3.14	45.81 ± 2.85	51.34 ± 4.87	55.51 ± 3.19	45.81 ± 2.84	-	Zamora *et al.* 2016[5]
	Search	5.3 ± 0.6	84.9 ± 53.0			53.1 ± 2.7	60.6 ± 1.0	48.4 ± 1.5	-	Arias-Aguilar *et al.* 2018[7]
P. cf. *rubiginosus*	Search	28.5 ± 0.5	187.6 ± 60.9	58.3 ± 0.7	53.8 ± 0.8	60.5 ± 0.1	60.8 ± 0.3	53.4 ± 0.6	5/1	This study[1]
	Approach	25.0 ± 5.2	79.4 ± 14.1	59.2 ± 1.1	56.0 ± 3.2	60.2 ± 0.6	60.6 ± 0.8	54.2 ± 3.1	49/4	This study[1]
P. parnellii species complex	Search	30.4	61.9				63.5	54.5	30	O'Farrell and Miller 1997[2]
	Search	21.23 ± 0.87		60.6 ± 0.08	48.05 ± 0.61	60 ± 0.17	60 ± 0.17	59.61 ± 0.16	67	Macías et al. 2006[8]
	Search	25.8 ± 3.1	48.0 ± 21.1			64.5 ± 1.0	64.6 ± 1.0	64.2 ± 1.1	25	MacSwiney *et al.* 2008[3]
	Search	15.8 ± 4.8	47.4 ± 37.7			53.9 ± 3.4	57.2 ± 0.5	46.7 ± 2.3	-	Arias-Aguilar *et al.* 2018[7]
	Search	21 ± 5.5	25 ± 15.6			58.2 ± 0.7	60.2 ± 0.8	46.3 ± 1.9	5	Pio et al. 2010[9]
	Search	27.8 ± 3.1	64.8	61.3 ± 1.8	55.7 ± 2.8	63.1 ± 1.1			-	Orozco-Lugo *et al.* 2013[6]
	Search	24.42 ± 3.7					64.73 ± 1.42	54.93 ± 1.61	388	Briones-Salas *et al.* 2013[4]
	Search	21.21 ± 4.97		61.93 ± 2.04	52.87 ± 2.20	63.61 ± 3.19	64.97 ± 1.27	52.86 ± 2.20	50	Zamora *et al.* 2016[5]

Appendix 2

Records of *Pteronotus* species in Colombia were obtained from the Biodiversity Information System of Colombia (SIB), Global Biodiversity Information Facility (GBIF), and biological collections. USNM: National Museum of Natural History, ICN: Instituto de Ciencias Naturales, FMNH: Field Museum of Natural History, ROM: Royal Ontario Museum, MHNG: Muséum d'histoire naturelle de la Ville de Genève, MUJ: Museo Javeriano de Historia Natural, CZUC-M: Colección Zoológica de la Universidad de Córdoba - Mamíferos, MHNLS: Museo de Historia Natural La Salle, MHNUCa: Museo de Historia Natural de la Universidad de Caldas, MHNU: Museo de Historia Natural Unillanos. *Specimen deposited in the Laboratory of Biology I – Universidad de Sucre.

Species	Department	Locality	Latitude	Longitude	Source	References
Pteronotus gymnonotus	Vichada	Santa Teresita			USNM 431554	GBIF 2021
	Córdoba	Corregimiento El Diluvio			ICN 2481	ICN online database
	Bolívar	Bocachica, Ruinas de San Angel (Cerro de La Popa). Salón en una galería.			ICN 1668	ICN online database
	Bolívar	Bahía de Cartagena, Isla de Tierra Bomba, Bocachica. Fuerte de San Fernando. En las galerías bajas laterales atravesando las bóvedas			ICN 2255	ICN online database
Pteronotus parnellii	Bolívar	Bocachica, Cartagena	10° 19' 60.0" N	75° 29' 40.9" W	FMNH 122063 - 122064	Chacón-Pacheco *et al.* 2018
	Bolívar	Cartagena	10° 23' 59.0" N	75° 30' 52.0" W	ROM 43984, 45303, 52542, 53999,	Chacón-Pacheco *et al.* 2018
	Bolívar	Isla Barú	10° 14' 23.8" N	75° 35' 46.4" W	MHNG 1922.023 - 1922.064	Chacón-Pacheco *et al.* 2018
	Cesar	Los Besotes, Valledupar	10° 34' 13.7" N	73° 16' 15.3" W	MUJ 1661	Chacón-Pacheco *et al.* 2018
	Guainía	Inírida	03° 50' N	67° 55' W	Ferrer-Pérez *et al.* 2009b	Chacón-Pacheco *et al.* 2018
	Huila	Baraya, Las Delicias	03° 09' 05.6" N	75° 01' 19.5" W	ICN 13589 - 13590	Chacón-Pacheco *et al.* 2018
	Huila	Tamarindo, Neiva	03° 03' 36.0" N	75° 22' 12.0" W	MUJ 655, 1003	Chacón-Pacheco *et al.* 2018
	Magdalena	PNN Tayrona	11° 18' 59.5" N	73° 56' 59.4" W	ICN 7822	Chacón-Pacheco *et al.* 2018
	Sucre	La Florida, San Marco	08° 35' 49.9" N	75° 08' 31.2" W	ICN 17441, 17442, 17443, 17444, 17445, 17446	Chacón-Pacheco *et al.* 2018
	Sucre	Estación Meteorológica Primates, Coloso	09° 31' 50" N	75° 21' 01" W	Montes *et al.* 2012	Chacón-Pacheco *et al.* 2018
	Sucre	Las Campanas, Coloso	09° 30' 00.0" N	75° 21' 00.0" W	FMNH 69367 - 69396	Chacón-Pacheco *et al.* 2018
	Tolima	Gualanday	04° 15' N	74° 59' W	Bejarano-Bonilla *et al.* 2007	Chacón-Pacheco *et al.* 2018
	Tolima	Pastales, Ibagué	04° 30' N	75° 18' W	Bejarano-Bonilla *et al.* 2007	Chacón-Pacheco *et al.* 2018
	Tolima	Boquerón, Ibagué	04° 24' 13.4" N	75° 11' 49.9" W	ROM 77274	Chacón-Pacheco *et al.* 2018
	Vichada	PNN El Tuparro, Administrative Center	05° 21' 07.8" N	67° 51' 15.1" W	ICN 12688	Chacón-Pacheco *et al.* 2018
	Córdoba	La Oscurana, Tierralta	08° 00' N	76° 05' W	ICN 19907, 19912	Chacón-Pacheco *et al.* 2018
	Córdoba	PNN Paramillo, Llanos del Tigre	07° 36' 49.5" N	76° 00' 44" W	MUJ 1520	Chacón-Pacheco *et al.* 2018
	Córdoba	PNN Paramillo, Zancó	07° 40' 02.5" N	076 °05' 50.5" W	MUJ 1523	Chacón-Pacheco *et al.* 2018
	Córdoba	Tuis Tuis, Tierralta	08° 02' 46.8" N	076° 05' 43.5" W	CZUC-M 0131, 0239	Chacón-Pacheco *et al.* 2018
	Córdoba	Cajón del Diablo, Tierralta	08° 17' 24.2" N	075° 59' 49.8" W	CZUC-M 0240, 0241	Chacón-Pacheco *et al.* 2018
	Guainía	Inírida			MHNLS	Ferrer-Pérez *et al.* 2009b
	Vichada	Puerto Carreño, Reserva Natural Privada Bojonawi	6° 5' 52.789" N	67° 28' 59.581" W	MHNUCa 1108	GBIF 2021
	Vichada	Puerto Carreño, Reserva Natural Privada Bojonawi	6° 5' 52.789" N	67° 28' 59.581" W	MHNUCa 1113	GBIF 2021
	Bolívar	Bahía de Cartagena, Isla de Tierra Bomba, Bocachica, Ruinas de San Angel, Cerro de La Popa, salón en galerías			ICN 2628-2677	ICN online database
	Cesar	San Martin	07º 53' 19,5" N	73º 39' 17,4" W	ICN 18892	ICN online database
	Cesar	El Paso			ICN 18893	ICN online database
	Bogotá	Ciudad de Bogotá			ICN 1533	ICN online database
	Huila	Baraya, Sitio El Cruce, finca Las Delicias	3° 9' 5.608" N	75° 1' 19.501" W	ICN 13589 - 13590	ICN online database
	La Guajira	Guajira, Albania, Valle del Cerrejón, Arroyo Bruno			ICN 19486	ICN online database
	Magdalena	Parque Nacional Natural Tayrona, Arrecifes	11° 19' 4.080" N	73° 56' 52.584" W	ICN 7822	ICN online database
	Magdalena	Parque Nacional Natural Tayrona, Gairaca	11° 19' 39.828" N	74° 6' 38.412" W	ICN 7823	ICN online database
	Magdalena	Colonia Agrícola de Caracolito			ICN 875	ICN online database
	Sucre	San Marcos, Vereda La Florida, ciénaga Gamboa, Granja Cocodrilia	8° 35' 49.901" N	75° 8' 31.194" W	ICN 17441-17446	ICN online database
	Vichada	Parque Nacional El Tuparro, alrededores del Centro Administrativo	5° 21' 7.751" N	-67° 51' 15.120" W	ICN 12688, ICN 13944	ICN online database

Appendix 2
Continuation

Species	Department	Locality	Latitude	Longitude	Source	References
	Antioquia	Turbo			Gardner 2007	Montes *et al.* 2012
	Antioquia	Boca Chica			Muñoz-Arango 2001	Montes *et al.* 2012
	Bolívar	Tierra Bomba			Muñoz-Arango 2001	Montes *et al.* 2012
	Bolívar	Cartagena			Muñoz-Arango 2001	Montes *et al.* 2012
	Cauca	El Bordo			USNM 595072	Montes *et al.* 2012
	Cundinamarca	Santa Fe de Bogotá			Muñoz-Arango 2001	Montes *et al.* 2012
	La Guajira	Nazaret			Gardner 2007	Montes *et al.* 2012
	Sucre	Tolúviejo			USNM 431459-431464	Montes *et al.* 2012
	Sucre	Colosó			*ADNO 0007	Montes *et al.* 2012
	Valle del Cauca	El Pital			USNM 595073	Montes *et al.* 2012
Pteronotus personatus	Vichada	Santa Teresita			USNM 431484-431488	Montes *et al.* 2012
	Meta	Restrepo	4° 15' 0.000" N	73° 34' 0.001" W	ROM 50142	GBIF 2021
	Vichada	Puerto Carreño, Vda Caño Negro			MHNU 406	GBIF 2021
	Vichada	Santa Teresita			USNM 431484-431486	GBIF 2021
	Bolívar	Bahía de Cartagena, Isla de Tierra Bomba, Bocachica, Fuerte de San Fernando, en las galerías laterales de la parte alta			ICN 2573-2627	ICN online database
	Bolívar	Castillo de San Fernando			ICN 3873-3902	ICN online database
	Bolívar	Bahía de Cartagena, Isla de Tierra Bomba, Bocachica, Ruinas de San Angel, Cerro de La Popa, salón en galerías			ICN 2676-2681	ICN online database
	Córdoba	Montería, Corregimiento El Diluvio			ICN 2686	ICN online database
	La Guajira	Hatonuevo			ICN 14950	ICN online database
	La Guajira	Albania			ICN 19487	ICN online database
	Nariño	Km 98 vía Tumaco. Río Nambí, cuenca río Telembí, Quebrada. Babosa, cuenca del río Patía			ICN 2722	ICN online database