








# Distribution extension of *Lasiurus arequipae* Málaga, Díaz, Arias & Medina, 2020 (Chiroptera, Vespertilionidae) and contributions to its natural history

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## Abstract

The recently described bat *Lasiurus arequipae* Málaga, Díaz, Arias & Medina, 2020 is endemic to Peru. *Lasiurus arequipae* is currently known to occur at two localities in the department of Arequipa and one locality in the department of Tacna in southwestern Peru. Here, based on morphological and molecular data, we present a fourth locality that represents the southernmost record of this species and extends its known range 62 km south from the nearest locality in Tacna. Additionally, we provide information some aspects on the natural history and acoustic profile of *L. arequipae*.

## Keywords

Echolocation call, Lasiurini, new record, Pacific coastal desert, Peruvian bats, Tacna

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## Introduction

Vespertilionidae Gray, 1821, is the most taxonomically diverse bat family in the world with more than 520 species (MMD 2021). Approximately 110 vespertilionid species occur in the Americas (Solari and Martínez-Arias 2014; Moratelli et al. 2019a). In Peru, the family is the third most diverse family, after Phyllostomidae and Molossidae, with 25 species grouped in four genera:

*Eptesicus* Rafinesque, 1820; *Lasiurus* Gray, 1831; *Myotis* Kaup, 1829; and *Rhogeessa* Allen, 1866 (Pacheco et al. 2021). The genus *Lasiurus* includes the red, yellow, and hoary fur bats and is easily distinguished from other genera by its wide palatal emargination (approximately a third of the distance across the canines) that separates the premaxillae and upper incisors, and by its

hairy uropatagium on its dorsal surface (Gardner and Handley 2008). Recently, Baird et al. (2015, 2017, 2021) suggested the division of *Lasiurus* into three genera based on molecular data and external differences in fur colors: *Lasiurus* (red bats), *Aeorestes* (hoary bats), and *Dasypterus* (yellow bats). This taxonomic arrangement has been disputed by Ziegler et al. (2016), Novaes et al. (2018), and Teta (2019), citing a lack of support for this division in a monophyletic genus and stating that using subgeneric names preserves the nomenclatural stability and facilitates the searching in databases, especially when *Aeorestes* had never been used as a name for hoary bats. In accordance with these publications, we recognize *Lasiurus* to include the subgenera *Aeorestes* and *Dasypterus*.

Twenty species of *Lasiurus* are currently recognized, and these are mostly distributed throughout the Americas, from Canada to Argentina. Moreover, vagrant records are also known in northern Canada, Bermuda, Hawaii, the Orkney Islands, and Iceland (Allen 1939; Hall and Jones 1961; Koopman and Gudmundsson 1966; Gardner and Handley 2008).

In Peru, *Lasiurus* is represented by four of the eight species occurring in South America and is distributed from sea level to 3300 m a.s.l. (Graham 1983; Málaga et al. 2020; Pacheco et al. 2021):

- *Lasiurus blossevillii* (Lesson & Garnot, 1826), is characterized by the gray tips of the hairs on the dorsal fur giving it a hoary or frosted aspect (Díaz et al. 2016) and occurs on both sides of the Andes in the Bosque Seco Ecuatorial, Bosque Tropical Amazónico, Bosque Tropical del Pacífico, Yungas, Páramo, Puna, and Desierto Costero ecoregions (Allen and Keays 1901; Thomas 1926; Ortiz de la Puente 1951; Graham and Barkley 1984; Solari et al. 2001; Quintana et al. 2009);
- *Lasiurus ega* (Gervais, 1856), characterized by its olivaceous yellow coloration, has also been recorded on both sides of the Andes in the Bosque Tropical Amazónico, Bosque Tropical del Pacífico, and the Yungas ecoregions (Hall and Jones 1961; Pirlot 1968; Gardner 1976; Woodman et al. 1991; Ascorra et al. 1996);
- *Lasiurus villosissimus* (E. Geoffroy St.-Hilaire, 1806), characterized by its large forearm (>50 mm) and frosted predominantly gray and yellowish fur, occurs on the east side of the Andes in the Yungas ecoregions (Sanborn 1953; Gardner 1976); and
- *Lasiurus arequipae* Málaga, Díaz, Arias & Medina, 2020, recently described, can be distinguished from the other three species by its medium-sized forearm (46.4–47.6 mm), dense fur, cinnamon to orangish dorsal coloration mixed with dark brown giving it a marbled appearance, blackish wing membrane, and reddish hairs covering the forearm and metacarpals. The separation of *L. arequipae* from its sister species has been confirmed by its position in a phylogeny based on the mitochondrial marker cytochrome

b (Cyt-b) and in a high genetic divergence (<9.4%) (Málaga et al. 2020).

*Lasiurus arequipae* was originally only known by three specimens, one male collected at the type locality in the coastal valley of Huatiapa at 725 m a.s.l. and two (one male and one female individual) from Chaucalla at 860 m a.s.l. in the department of Arequipa. Most recently, this species was also reported for Lomas de Sama Grande at 555 m a.s.l., department of Tacna, collected while roosting in an olive tree (Mamani-Contreras and Aragón-Alvarado 2021). *Lasiurus arequipae* is the only species of *Lasiurus* endemic to Peru, and the second species of *Lasiurus* recorded in the Desierto Costero ecoregion where only *L. blossevillii* had been known. Ugarte-Núñez (2020) developed an echolocation key to 20 species of bats from the Pacific coast and the western slopes of the Andes of southern Peru, including *L. arequipae*, but did not provide the location and the source of the acoustic records. The echolocation patterns described of *L. arequipae* show peak frequencies of ~35 kHz and a descending modular frequency at the beginning and at the end, with a middle portion close to the quasi-constant frequency, supporting the distinction of *L. arequipae* from other species of *Lasiurus* (Briones-Salas et al. 2013; Rodríguez-San Pedro and Simonetti 2013; Rodríguez-San Pedro et al. 2014, 2016; Rivera et al. 2015).

Here, based on morphological and molecular data, we report new specimens of *L. arequipae* from the department of Tacna, Peru, extending the known distribution of the species further south from Lomas de Sama Grande and from its type locality. We also provide information on its natural history and echolocation calls.

## Methods

We sampled bats in Sama Valley, department of Tacna, Peru from the wet local season in 2015 to the wet local season in 2016. This valley, in which the Sama River flows, is in the Desierto Costero ecoregion. Xeric vegetation grows in the cracks and dry riverbeds of this desert region (Jaén et al. 1963; Morris and Panty 1999). We established six sampling stations with seven mist-nets (12 × 2.5 m) each. The nets were set perpendicular to the Sama River. The sampling was carried out for four consecutive nights per station during both wet and dry seasons. Sampling was performed at each station for 11 hours after sunset. The total sampling effort total was 336 net-nights. This research was authorized by the Servicio Nacional Forestal y de Fauna Silvestre (SERFOR) through R.D. N°246-2017-SERFOR/DGGSPFFS and authorization code for scientific purposes AUT-IFS-2017-057.

Our two collected specimens (one male, one female) were identified as *Lasiurus* based on morphological characters described by Díaz et al. (2016) and then compared with specimens deposited in the Museo de Historia Natural de la Universidad Nacional Mayor de San

Marcos (MUSM). The specimens went unidentified to species until after the description of *L. arequipae* (Málaga et al. 2020).

Our specimens are deposited at MUSM. Both specimens are preserved in ethanol. In the field, external measurements were taken using Fowler 54-100-444 Sylvac Ultra-Cal Mark IV digital calipers with an accuracy of 0.01 mm; these measurements included the head-body length (HB), tail length (T), hindfoot length (HF), ear length (E), and forearm length (FA). Both individuals were weighed using a 50 g Pesola spring scale to the nearest 0.1 g. The skull of the female specimen was removed and cleaned, and the following craniodental measurements were taken with the same calipers, also recorded to the nearest 0.01 mm: greatest length of the skull (GLS), condyle-basal length (CBL), zygomatic breadth (ZB), interorbital breadth (IB), postorbital constriction (POC), mastoid breadth (MAB), braincase breadth (BCB), palatal length (PL), maxillary tooththrow length (C-M), upper canine breadth (C-C), upper molar breadth (M-M), lower tooththrow length (c-m), and greatest length of mandible (GML). The craniodental measurements follow Barquez et al. (1999) and Málaga et al. (2020).

DNA was extracted from a fragment of muscular tissue preserved in alcohol 96° GL of the specimen MUSM 52933 using the GeneON “Vivantis” kit (GF-TD-100). A fragment of the cytochrome b gene (Cyt-*b*) was amplified using primers glo7L (5'-CAY-CGTTGTATTTCAACTRTAAGAAC-3') and glo6H (5'-CGGTGTAATGRATATACTACATRG-3'). We followed the thermal profile described in Hoffmann and Baker (2001) for PCR, and the amplification product was sent for sequencing only with the forward primer at MacroGen, Inc (Seoul, South Korea). We obtained 778 bp of Cyt-*b* and deposited the sequence at GenBank (accession code OK030950).

A phylogenetic analysis was performed using the sequence obtained in this study and 34 sequences were retrieved from GeneBank, which had previously been used by Baird et al. (2015) and Málaga et al. (2020). These sequences belong to the 16 species of *Lasiurus* and are listed in the Appendix, Table A1. Sequences of *Tadarida brasiliensis* (I. Geoffroy St.-Hilaire, 1824) and *Myotis velifer* (J.A. Allen 1890) were included as outgroups. The sequences were aligned in Geneious v. 7.12.3 using the ClustalW algorithm (Thompson et al. 1997). The final alignment had 1040 bp. The phylogenetic analyzes were performed using the maximum likelihood (ML) and Bayesian inference (BI) methods. For the ML analysis we used RAxML v. 7.2.8 (Stamatakis 2014) using GTRGAMMAI as the nucleotide substitution model and 1,000 pseudo-replications for bootstrapping and nodal support. For the BI analysis, the best nucleotide substitution model was estimated using jModelTest (Darriba et al. 2012) using three schemes of substitution (= 24 models) and the Akaike Information Criterion (AIC). The best model was HKI+I+G, which was implemented in MrBayes v. 3.2.7 (Ronquist et al.

2012) using four independent MCMC runs, 10 million generation sampled every 1,000 generation to estimate the posterior probabilities as nodal support. We considered 25% of the samples as burn-in. Convergences of the Bayesian analysis were checked on Tracer v. 1.6 and followed the recommendations described in the MrBayes manual: standard deviation less than 0.01 (it was 0.008), the potential scale reduction factor (PSRF) near to 1.0 (it was 0.99–1.0), and the effective samples size (ESS) more than 200 (it was 6000). Finally, genetic distance was estimated with Kimura 2-parameters (Kimura 1980) in MEGA v. 7.0.14 (Kumar et al. 2016). The phylogenetic tree was visualized in FigTree v. 1.3.4 and edited in Inkscape v. 0.9.

The lack of information about the acoustic records for this species, apart from the information provided by Ugarte-Núñez (2020), motivated us to provide complementary data. In Chaupo (Quechualla district, Arequipa), an individual with similar external characteristics (medium FA = 47.1 mm and the orange coloration in dorsal fur) to *L. arequipae* was captured in a mist-net; it was released following the methodologies of Kunz and Parsons (2009) and Estrada-Villegas et al. (2013), in order to perform acoustic recordings after the bat started to fly. Additionally, in Velinga (Quechualla district) and Sogay (Yarabamba district), bat acoustic recordings were made without capture. The recordings were made using two devices: Echo Meter 3 (Wildlife Acoustics) and Anabat Walkabout (Titley Scientific); both with a full-spectrum 16-bit resolution and a sampling quotient of 384 kHz set at 10 sec.

To define the main acoustic parameters of the searching calls obtained, the echolocation analysis was made using Raven Pro v. 1.5. (Center for Conservation Bioacoustics, Cornell Lab 2014). Parameters like peak frequency (PF), minimum frequency (LF), maximum frequency (HF), bandwidth (BW) were given in kilohertz (kHz), while call duration (CD) and inter-pulse (IP) were given in milliseconds (ms).

We developed a distribution map for the four species of *Lasiurus* distributed in Peru with ArcMap v. 10.3 using the material we examined at MUSM, as well as bat records of Peruvian specimens available in the scientific literature and deposited in the following collections: Academy of Natural Sciences of Philadelphia (ANSP, USA), American Museum of Natural History (AMNH, USA), Colección Biológica Tacna (CBT, Peru), Field Museum of Natural History (FMNH, USA), Louisiana State University Museum of Zoology (LSUMZ, USA), Museo de Historia Natural de la Universidad Nacional San Agustín de Arequipa (MUSA, Peru), Museum of Comparative Zoology from Harvard University (MCZ, USA), Royal Ontario Museum (ROM, Canada), University of California, Berkeley, Museum of Vertebrate Zoology (MVZ, USA), Texas Cooperative Wildlife Collection at Texas A&M University (TCWC, USA). Localities are listed in Appendix.



## Results

Morphological and molecular analyses confirm that the *Lasiurus* specimens collected in the Sama Valley (Tacna, Peru) are *L. arequipae*. Moreover, based on bioacoustic monitoring and the parameters of the echolocation calls, the specimens recorded at Chaupo, Velinga, and Sogay corresponds also to *L. arequipae*.

**Material examined.** PERU – **Tacna/Tacna** • Inclán district, 1 km N of Tomasiri; 17°49'58.20"S, 070°30'41.04"W; 464 m a.s.l.; 04.VIII.2015; G. Portugal leg.; mist-net; 1 adult ♀, fluid-preserved in alcohol with the skull removed, MUSM 52933 • Inclán district, 1 km N of Tomasiri; 17°49'58.20"S, 070°30'41.04"W; 464 m a.s.l.; 22.V.2016; G. Portugal leg.; mist-net; 1 adult ♂; fluid-preserved in alcohol, MUSM 52934 – **Arequipa/La Unión** • Quechualla district, Chaupo; 15°15'11.62"S, 072°59'1.42"W; 2058 m a.s.l.; 20.XI.2020; J. Ugarte leg.; obs; 1 adult – **Arequipa/La Unión** • 1 acoustic recording; Quechualla district, Velinga; 15°16'27.29"S, 073°01'37.37"W; 1719 m a.s.l.; 03.V.2018; J. Ugarte leg.; ultrasound detector – **Arequipa/Arequipa** • 1 acoustic recording; Yarabamba district, Sogay; 16°34'13.92"S, 071°24'45.75"W; 2730 m a.s.l.; 07.XII.2019; J. Ugarte leg.; ultrasound detector.

The locality, north of Tomasiri, is in a 1 km wide alluvial plain having a narrow riparian forest and a broad expanse of agricultural crops. One side of the river is restricted by a hillside about 50 m high. The individuals we captured were a non-lactating female and a male with descended testes.

**Identification.** The two individuals, MUSM 52933 (♀) (Fig. 1) and MUSM 52934 (♂), fit the description of *L. arequipae* (see Málaga et al. 2020). This is supported by a dense dorsal fur that varies from cinnamon-brown to orange. The dorsal hairs are tricolored (black basal band, yellowish mid-band, and dark brown tips), giving a marbled appearance to the fur. The ventral fur hairs are bicolored (black base and yellowish tips). Wing membranes are blackish with red hairs on both sides of the forearms and metacarpals. Cranio-dental measurements were also within the range provided by Málaga et al. (2020) (Table 1). The anterior border of the nasal bones is V-shaped. The shape of the ocular orbit is oval in dorsal view; the post palatal process is poorly developed; the mesopterygoid fossa is V-shaped; and the tympanic ring is circular in shape (Fig. 2). External measurements are given in Table 1.

The phylogenetic reconstruction with ML and BI analyses found that our Tacna specimen is sister to the only published sequence of *L. arequipae* (MUSA 21958). Moreover, the 778 bp of Cyt-*b* of these specimens from Tacna and Arequipa are 99.23% similar, while their K2p intraspecific genetic distance is less than 0.01% (Fig. 3).

Acoustic recordings of a Chaupo individual caught, then released, show that the echolocation call had a downward modulate frequency harmonic (FM-d) and



**Figure 1.** Adult female specimen of *Lasiurus arequipae* (MUSM 52933) collected with a mist net in the Sama Valley, 1 km from Tomasiri, Inclán district, Tacna, Peru.

**Table 1.** External and cranial measurements (in mm) and weight (in g) of the new records of *Lasiurus arequipae* (MUSM 52933, MUSM 52934), including the specimens given in Málaga et al. (2020).

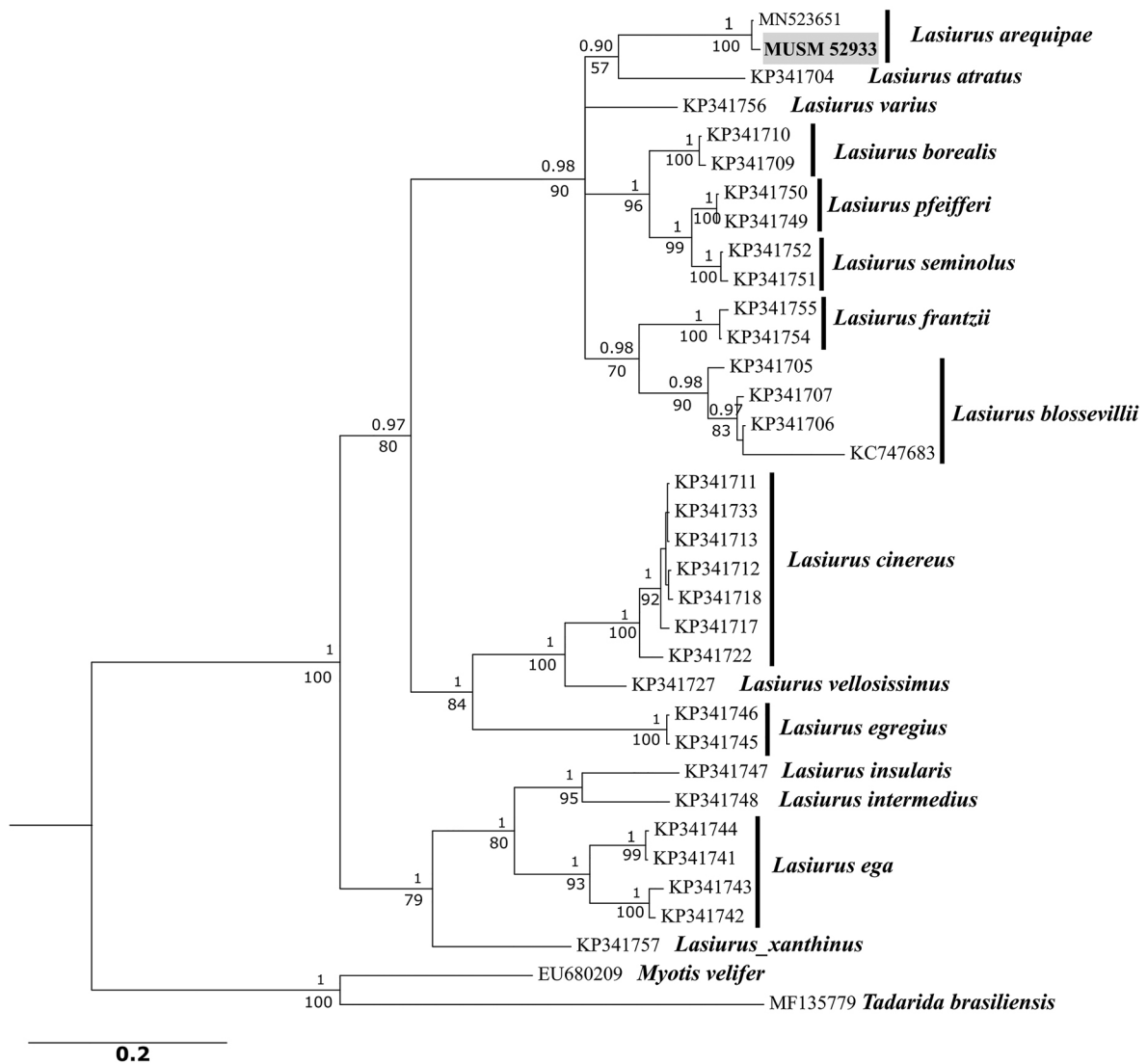
Measure- ment	MUSM 52934*	MUSM 52933*	MUSA 21058†	MUSA 21853†	MUSA 21891†
Sex	M	F	M	M	F
HB	114	118	120	106	123
TaL	60	60.5	60	56	64
HFL	8.5	9	10.3	8.6	11
EL	13	14	12.9	11	13
FAL	46	46.5	46.4	46.7	47.6
W	11	13	13	12	12
GLS	14.1	—	14.2	13.7	14.3
CBL	13.86	—	14.1	14	14.5
ZA	10.74	—	10.8	10.2	10.8
IB	—	—	6.4	6.1	6.4
POC	4.85	—	5	4.9	4.9
MW	8.39	—	8.9	8.6	8.9
BB	7.86	—	8.1	7.9	8
MxTL	5.11	—	5	4.9	5.2
PL	—	—	5.2	4.7	5.3
MnTL	5.97	—	5.8	5.8	6.1
ML	10.96	—	10.8	10.4	11.1
C-C	5.96	—	5.4	5.4	5.8
M3-M3	7.19	—	6.5	6.6	6.8

\* This study.

†Málaga et al. (2020).



**Figure 2.** Dorsal, ventral, and lateral views of the skull and mandible of *Lasiurus arequipae* (MUSM 42359). Scale bar: 5 mm.



**Figure 3.** Phylogenetic tree based on Cyt-b sequences of *Lasiurus* including our new record of *Lasiurus arequipae* (MUSM 52933). BI posterior probabilities are placed above the branch and ML bootstrap values below the branch.

occasionally a second harmonic of low density. Features and acoustic patterns we observed in this individual were similar to recordings obtained in Velinga and Sogay. The

characteristics and acoustic patterns described for the echolocation calls obtained at our study sites had a minimum frequency of  $19.27 \text{ kHz} \pm 2.41$ , maximum frequency

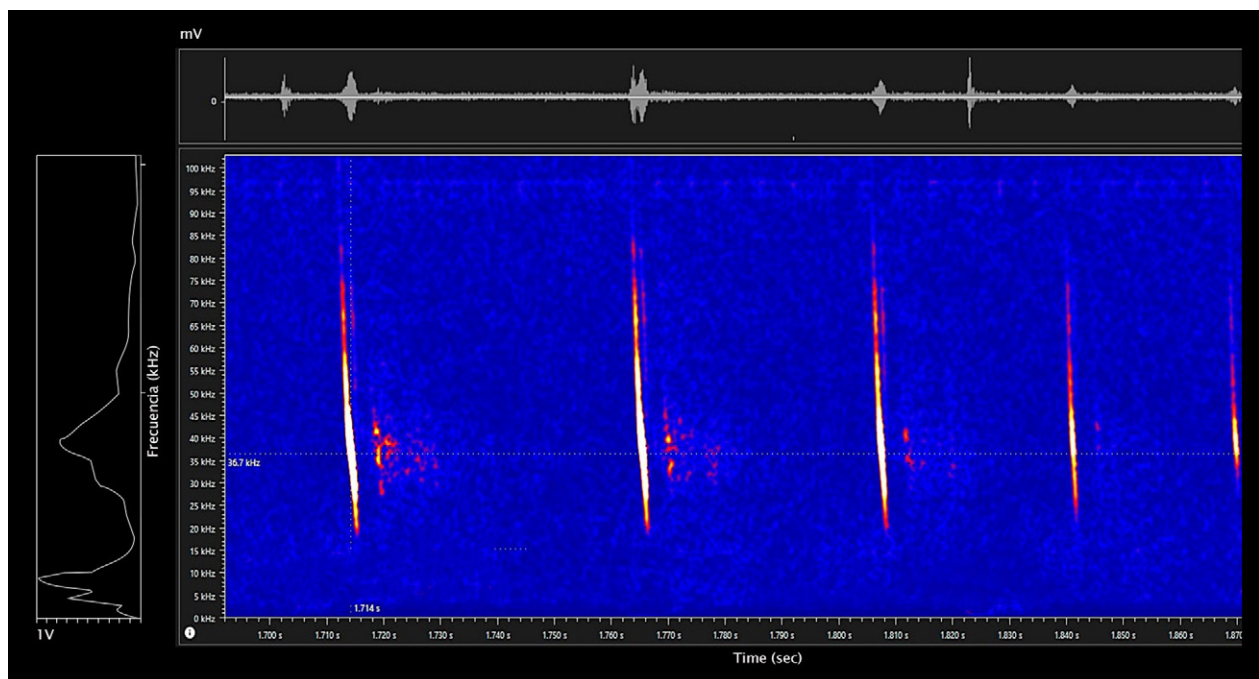
of  $75.56 \text{ kHz} \pm 11.78$ , and a frequency peak of  $35.39 \text{ kHz}$ . The average length of the call was  $3.97 \text{ ms} \pm 1.23$  with an interval of  $91.31 \text{ ms} \pm 46.69$ , and a bandwidth of  $56.29 \text{ kHz} \pm 12.78$  (Fig. 4). These calls are typical of vespertilionids and are in the parameters for *Lasiurus* (Schnitzler and Kalko 2001), which has a marked difference among the acoustic data of *L. varius* Poeppig, 1835, *L. cinereus* (Palisot de Beauvois, 1796), and *L. blossevillii* (Briones-Salas et al. 2013; Rodríguez-San Pedro and Simonetti 2013; Rodríguez-San Pedro et al. 2014, 2016; Rivera et al. 2015) (Table 2).

The map (Fig. 5) displays the current distribution of the *Lasiurus* species in the Peruvian territory: *Lasiurus arequipae*, *Lasiurus blossevillii*, *Lasiurus ega*, and *Lasiurus villosissimus*.

## Discussion

Our records of *Lasiurus arequipae* from Sama Valley in Tacna extends the known geographic distribution of this species about 292 km south of its type locality and 62

km south from its occurrence at Lomas de Sama Grande, department of Tacna. The Sama Valley, belonging to the Desierto Costero ecoregion, has typical features of Peruvian coastal valleys, with moderate slopes (greater than  $60^\circ$ ), warm temperatures ( $15\text{--}24^\circ\text{C}$ ), and little, irregular precipitation (Málaga et al. 2020; Portugal-Zegarra et al. 2020). These climatic and geographic characteristics are also present in northern coastal Chile, such as in the Lluta and Azapa valleys (less than 100 km from Sama Valley), where other species like *Platylina genovensium* Thomas, 1928, *Promops davisoni* Thomas, 1921, and *Nyctinomops aurispinosus* (Peale, 1848), were recently confirmed to occur (Ossa et al. 2016, 2018; Rodríguez-San Pedro et al. 2022). Therefore, *L. arequipae* may occur to this area or even further south. Moreover, discovery of *L. arequipae* in the Desierto Costero partially fills a known geographic gap for the genus, which extends from the Atacama Desert in northern Chile (where only *L. villosissimus* is known) to the Central Peruvian desert (where only *L. blossevillii* is known); no other *Lasiurus* species have been recorded before. It is unknown if *L. arequipae*



**Figure 4.** Echolocation calls of a free-flying individual of *L. arequipae* from Arequipa (Sonogram, oscillogram, and power spectrum).

**Table 2.** Comparison of the echolocation calls obtained of *Lasiurus arequipae* with other *Lasiurus* species (PF, LF, HF, and BW in kHz; CD and IP in ms).

<i>Lasiurus</i> species	Peak frequency (PF)	Minimum frequency (LF)	Maximum frequency (HF)	Bandwidth (BW)	Length (CD)	Interpulse (IP)
<i>L. arequipae</i>	$35.39 \pm 3.44$	$19.27 \pm 2.41$	$75.56 \pm 11.78$	$56.29 \pm 12.78$	$3.97 \pm 1.23$	$91.31 \pm 46.69$
<i>L. blossevillii</i> <sup>*A</sup>	38.77	$43.58 \pm 1.36$	$62.89 \pm 8.14$	—	$6.11 \pm 1.67$	—
<i>L. cinereus</i> <sup>†,§</sup>	30	24	43	—	7.50	—
<i>L. varius</i> <sup>†</sup>	$41.06 \pm 0.52$	$37.47 \pm 0.34$	$52.73 \pm 0.99$	$15.26 \pm 0.77$	$4.91 \pm 0.18$	$157.80 \pm 9.74$

<sup>\*</sup>Briones-Salas (2013).

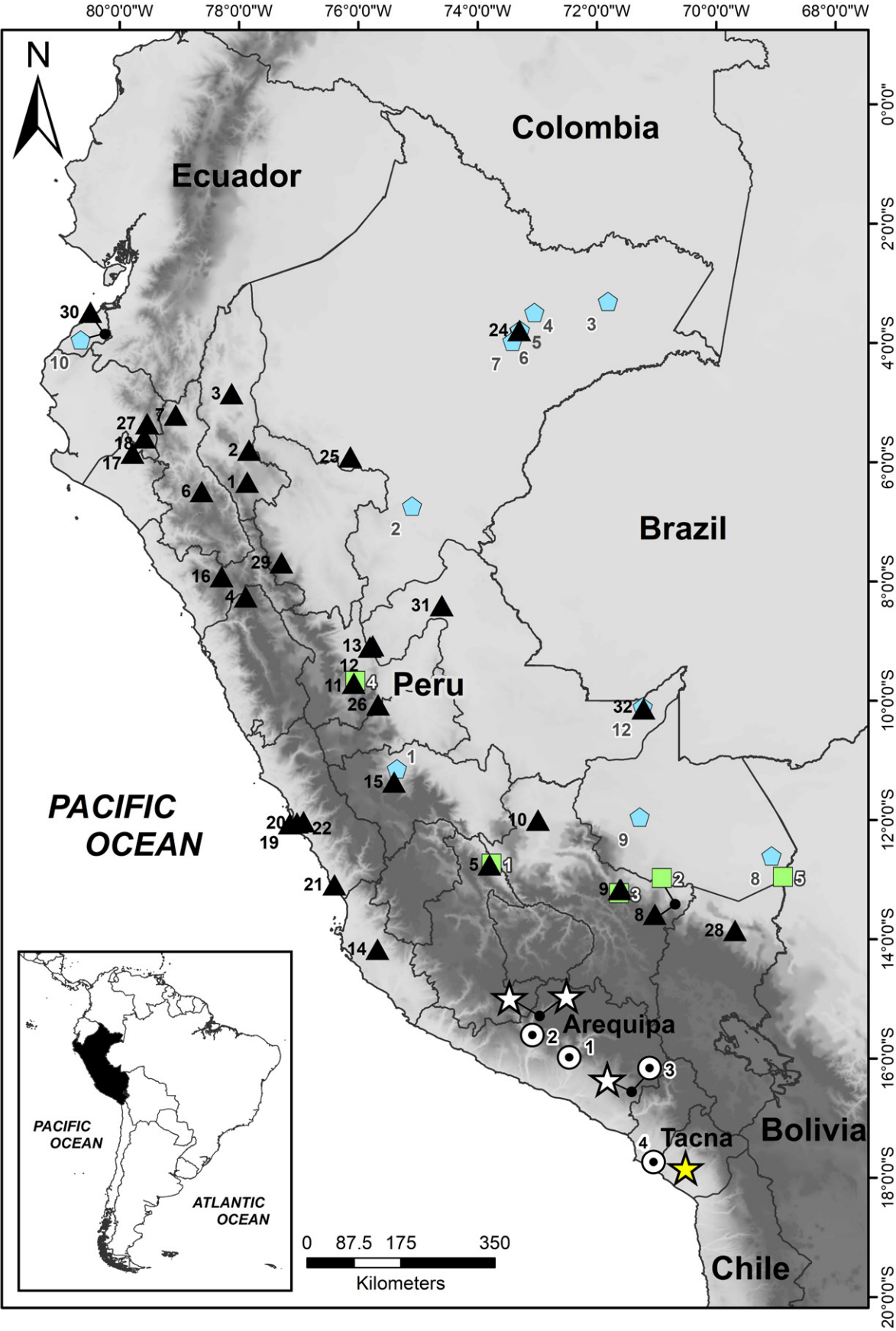
<sup>†</sup>Rodríguez-San Pedro (2013).

<sup>‡</sup>Rodríguez-San Pedro (2014).

<sup>§</sup>Rodríguez-San Pedro (2016).

<sup>A</sup>Rivera (2015).





**Figure 5.** Geographic distribution of species of *Lasiurus* occurring in Peru. Yellow star: two new records of *Lasiurus arequipae* (MUSM 52933, MUSM 52934) from Sama Valley, 1 km north of Tomasiri, Inclán district, Tacna department, Peru. White stars: acoustic records not detailed in Ugarte-Núñez (2020); green squares: records of *Lasiurus blossevillii*; blue pentagons: records of *Lasiurus ega*; black triangles: records of *Lasiurus villosissimus*. Additional details of the records are provided in the Appendix.

may occur in sympatry with *L. blossevillii*, *L. villosissimus*, or both, and if the more northern *L. villosissimus* might also be found in the southern Peruvian desert.

*Lasiurus arequipae* has been described as occurring at 555–860 m a.s.l. (Málaga et al. 2020; Mamani-Contreras and Aragón-Alvarado 2021), although Málaga et al. (2020) mentioned the possibility that it may occur at 2760 m a.s.l. based on an individual collected in Sogay (Arequipa) but released. Our records from Sama valley, at 464 m a.s.l., are the lowest known occurrences of the species, while our echolocation surveys confirm the highest record of *L. arequipae*, at 2730 m a.s.l. in Yarabamba.

Our new acoustic data of *L. arequipae* allowed us to differentiate this species from *L. blossevillii*. Thus, *L. arequipae* has a lower peak frequency ( $35.39 \text{ kHz} \pm 3.44$ ) and a distinctive major bandwidth, as well as a significant lower minimum frequency. The length of the call of *L. arequipae* is shorter than the other *Lasiurus* species. Therefore, the acoustic parameters of *L. arequipae* do not overlap or approach those of the other species within their geographic distribution. Schnitzler and Kalko (2001) pointed out that bats with longer signals of low frequency would be adapted for large prey detection at long distances, which would apply for *L. arequipae*.

Among the *Lasiurus* species in Peru (Fig. 5), *L. blossevillii* has a wider distribution and a preference for lowland forests, highland forests, the Puna, the Yungas, and even the Pacific Coastal Desert (Allen and Keays 1901; Thomas 1926; Ortiz de la Puente 1951; Graham and Barkley 1984; Solari et al. 2001; Quintana et al. 2009). The distribution of *L. ega* is restricted to ecosystems of the Bosque Tropical del Pacífico, Bosque Tropical Amazónico, and the Yungas (Hall and Jones 1961; Piriot 1968; Gardner 1976; Woodman et al. 1991; Ascorra et al. 1996), while *L. villosissimus* has been recorded in the Yungas (Sanborn 1953; Gardner 1976). The distribution of insectivorous bat species like *Lasiurus* corresponds to temperature and altitude because of ecophysiological tolerances and thermoregulation (Pérez 2011). In this context, the three species converge in similar environments to the eastern Andean slopes and the lowland forests of Argentina, Bolivia, Brazil, Peru, and Uruguay, with *L. blossevillii* most adapted to higher altitudes and extreme environmental conditions.

The records of *L. arequipae* provided by Málaga et al. (2020), Mamani-Contreras and Aragón-Alvarado (2021), and us, suggest a great adaptation to the aridity of the Pacific coastal desert. Moreover, *L. arequipae* could be taking advantage of agricultural areas mentioned by Mamani-Contreras and Aragón-Alvarado (2021) as roosts. Therefore, additional efforts are needed to understand the use of natural and anthropic areas by *L. arequipae* and other species of *Lasiurus*. The recent description of *L. arequipae* and our new records demonstrate the underestimation of species diversity within *Lasiurus*. Our data improve knowledge of bat diversity and distribution in the Coastal Desert ecoregion of Peru, where four species, *Tomopeas ravus* Miller, 1900, *Eumops*

*chiribaya* Medina, Gregorin, Zeballos, Zamora & Moras, 2014, *Eptesicus (Histiotus) mochica* Velazco, Cunha, Cláudio, Giménez & Giannini, 2021, and *Myotis bakeri* Moratelli, Novaes, Carrión Bonilla & Wilson, 2019, together with *L. arequipae* are endemic to this Peruvian ecosystem (Medina et al. 2014; Loaiza and Pacheco 2017; Moratelli et al. 2019b; Málaga et al. 2020; Mamani-Contreras and Aragón-Alvarado 2021; Velazco et al. 2021).

Finally, we suggest that additional fieldwork must be conducted to the north and the south of the currently known distribution of *L. arequipae*, where this species could be facing threats from mining and urban expansion, similar to other insectivores such as *Myotis atacamensis* (Lataste, 1892), *Amorphochilus schnablii* Peters, 1877, and *Promops davisoni* (Aragón-Alvarado and Aguirre 2014; Flores-Quispe et al. 2015).

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## Authors' Contributions

Conceptualization: GCM, GPZ, PSV, MFQ. Data curation: PSV, MFQ, GCM, JUN. Formal analysis: PSV, JUN, GCM. Funding acquisition: PSV. Investigation: MFQ, GCM, GPZ, PSV. Methodology: GPZ, MFQ, PSV, GCM, JUN. Resources: GPZ. Software: PSV, JUN, GCM. Supervision: MFQ. Validation: PSV, JUN. Writing – original draft: GPZ, MFQ. Writing – review and editing: GPZ, GCM.

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## Appendix

### Records of specimens used to map the distribution of *Lasiurus* in Peru (Figure 5).

Records obtained from the scientific literature include Allen (1901), Thomas (1926), Ortiz de la Puente (1951), Sanborn (1953), Handley (1960), Pirlot (1968), Gardner (1976), Graham and Barkley (1984), Woodman et al. (1991), Ascorra et al. (1996), Solari (2001), Hice et al. (2004), Quintana et al. (2009), Leal and Gomes-Silva (2015), and Málaga et al. (2020), Mamani-Contreras and Aragón-Alvarado (2021); these are indicated with superscript numbers from 1 to 16, respectively. The full name of the acronyms of the scientific collections are detailed in the Methods section.

#### *Lasiurus arequipae*

PERU – **Arequipa**: (1) Huatiapa, 15°58'S, 072°27'W (MUSA 21058<sup>15</sup>); (2) Chaucalla, 15°36'S, 073°04'W (MUSA 21853, 21891<sup>15</sup>); (3) Yarabamba, 16°34'S, 071°24'W (Released<sup>15</sup>); Chaupo, 15°15'S, 072°59'W (Released, Acoustic\*); Velinga, 15°16'S, 073°01'W (Acoustic\*); Sogay, 16°34'S, 071°24'W (Acoustic\*) – **Tacna**: Lomas de Sama Grande, 07°45'S, 071°05'W (CBT 529<sup>16</sup>); Inclán, 17°49'S, 070°30'W (MUSM 52933, 52934)\*.

#### *Lasiurus blossevillii*

PERU – **Amazonas**: (1) Condechaca, 24 km al S de Chachapoyas, 06°19'S, 077°51'W (the place of deposit of this specimen is unknown<sup>3</sup>); (2) Corosha, Copal, 05°47'S, 077°49'W (MUSM 46923\*); (3) 43 km NE of

Chiriaco, 04°50'S, 078°07'W (LSUMZ 21507, 21508)\* – **Ancash:** (4) Conchucos, Cochaconchucos, 08°15'S, 077°53'W (MUSM 40083\*) – **Ayacucho:** (5) Yuraccyacu, 12°45'S, 073°48'W (LSUMZ 16636\*) – **Cajamarca:** (6) 3 km al E de Chota, 06°29'S, 078°37'W (LSUMZ 22322\*); (7) Tabaconas, 4 km al O de El Chaupe, 05°12'S, 079°03'W (MUSM 10649\*). **Cusco:** (8) Quispicanchi, Hacienda Cadena, 13°24'S, 070°43'W (FMNH 68467\*); (9) Kosñipata, Pillahuata, 13°09'S, 071°37'W (MUSM 19474, FMNH 172159)\*; (10) Echarate, 11°59'S, 072°59'W (MUSM 38814, MUSM 38815)\* – **Huánuco:** (11) Cordillera de Carpish, 09°42'S, 076°04'W (LSUMZ 12588\*); (12) 5 km al NE de Tingo María, 09°05'S, 075°48'W (LSUMZ 12589\*); (13) 35 km al NE de Tingo María, Santa Elena, 09°04'S, 075°45'W (LSUMZ 14311\*). **Ica:** (14) Pachacutec, Fundo La Catalina, 14°09'S, 075°40'W (MUSM 37770\*) – **Junín:** (15) Tarma, Maraynioc, 11°21'S, 075°24'W (MCZ 38587\*) – **La Libertad:** (16) Quiruvilca, Río Perejil, 07°54'S, 078°17'W (MUSM 41901\*) – **Lambayeque:** (17) 12 km al N de Olmos, 05°50'S, 079°46'W (LSUMZ 21302\*); (18) 44 km N Olmos, San Isidro, 05°35'S, 079°35'W (LSUMZ 21818\*). **Lima:** (19) Callao, 12°03'S, 077°08'W (MUSM 953\*); (20) Lima, 12°02'S, 077°01'W (MUSM 6050<sup>3</sup>), (21) Cañete, 13°04'S, 076°24'W (LSUMZ 16635\*); (22) Ate, Vitarte, 12°01'S, 076°55'W (MUSM 7180\*), (23) Lima, Universidad Agraria “La Molina”, 12°04'S, 076°56'W (MUSM 16128\*) – **Loreto:** (24) San Juan Bautista, km 1 de la carretera Iquitos-Nauta, 03°47'S, 073°17'W (MUSM 30027\*); (25) Yurimaguas, Pijuyo, 05°54'S, 076°08'W (MUSM 46923\*) – **Pasco:** (26) Pozuzo, Santa Virginia, 10°03'S, 075°40'W (MUSM 12675\*). **Piura:** (27) 4 km al SO de Cascapamba, Los Peroles, 05°20'S, 079°32'W (ROM 125163\*) – **Puno:** (28) San Román, Juliaca, Minas Incas, 13°51'S, 069°40'W (AMNH 16565<sup>1</sup>) – **San Martín:** (29) Parque Nacional Río Abiseo, Las Papayas, 07°40'S, 077°17'W (MUSM 7269, 7270)<sup>10</sup> – **Tumbes:** (30)

Pampas de Hospital, Quebrada Faical, 03°49'S, 080°15'W (MUSM 19328\*) – **Ucayali:** (31) Pucallpa, 08°24'S, 074°36'W (TCWC 12755\*); (32) Balta, Río Curanja, 10°07'S, 071°13'W (MVZ 136563\*; LSUMZ 14312<sup>6</sup>, 14313\*).

### *Lasiurus ega*

PERU – **Junín:** (1) San Ramón, San Ramón, Agua Blanca, 11°08'S, 075°21'W (MUSM 20784\*) – **Loreto:** (2) Ucayali, Sarayacu, 06°43'S, 075°06'W (AMNH 76257<sup>5</sup>); (3) Mariscal Ramón Castilla, Pebas, 03°18'S, 071°49'W (ANSP 5765, 5766, 5767<sup>5</sup>); (4) Puerto Indiana, 03°29'S, 073°03'W (the place of deposit of this specimen is unknown)<sup>11</sup>; (5) km 1 de la carretera Iquitos-Nauta, Club Social Sanmartinense, 03°47'S, 073°17'W (MUSM 30028\*); (6) Maynas, San Juan Bautista, 03°46'S, 073°17'W (MUSM 33408\*); (7) Reserva Nacional Allpahuayo-Mishana, 03°57'S, 073°24' (the place of deposit of this specimen is unknown)<sup>13</sup> – **Madre de Dios:** (8) Tambopata, Albergue Cuzco Amazónico, 12 km al E de Puerto Maldonado, 12°36'S, 069°04'W (MUSM 924\*, MVZ 168934<sup>9</sup>); (9) Parque Nacional Manu, Estación Biológica Pakitza, 11°56'S, 071°17'W (MUSM 12437<sup>12</sup>). **Tumbes:** (10) Pampas de Hospital, Quebrada Faical, 03°49'S, 080°15'W (MUSM 10736\*) – **Ucayali:** (11) Balta, Río Curanja, 10°07'S, 071°13'W (LSUMZ 14314, 14315, 14316)<sup>7</sup>, (12) Balta, Río Curanja, 10°06'S, 071°14' (the place of deposit of this specimen is unknown)<sup>29</sup>.

### *Lasiurus villosissimus*

PERU – **Ayacucho:** (1) San José, Río Sta. Rosa, 12°43'S, 073°46'W (LSUMZ 16637<sup>7</sup>) – **Cusco:** (2) Quispicanchi, Limacpunco, 13°24'S, 070°43'W (FMNH 78685<sup>4</sup>); (3) Paucartambo, 13°13'S, 071°37'W (MUSM 6731\*) – **Huánuco:** Zapatogocha above Acomayo, 09°40'S, 076°03'W (LSUMZ 17900)<sup>7</sup> – **Madre de Dios:** Tambopata, Santuario Nacional Pampas del Heath, Refugio Juliaca, Pampa Sur, Aguajal, 12°57'S, 068°52'W (MUSM 11671\*).

**Table A1.** Sequences of *Lasiurus* species included in our molecular analysis.

Species	GenBank accession no.	Voucher	Country	Cyt-b	Source
<i>Lasiurus arequipae</i>	—	MUSM 52933	Peru	778	Present study
<i>Lasiurus arequipae</i>	MN523651	BMT-027	Peru	1140	Baird et al. 2015
<i>Lasiurus atratus</i>	KP341704	F54400	Guyana	1140	Baird et al. 2015
<i>Lasiurus varius</i>	KP341756	AK16070	Argentina	1140	Baird et al. 2015
<i>Lasiurus borealis</i>	KP341710	AK21073	EE.UU.	1140	Baird et al. 2015
<i>Lasiurus borealis</i>	KP341709	AK21072	EE.UU.	1140	Baird et al. 2015
<i>Lasiurus pfeifferi</i>	KP341750	TK32029	Cuba	1140	Baird et al. 2015
<i>Lasiurus pfeifferi</i>	KP341749	TK32016	Cuba	1140	Baird et al. 2015
<i>Lasiurus seminolus</i>	KP341752	AK21348	EE.UU.	1140	Baird et al. 2015
<i>Lasiurus seminolus</i>	KP341751	AK01565	EE.UU.	1140	Baird et al. 2015
<i>Lasiurus frantzii</i>	KP341755	F34142	Guatemala	707	Baird et al. 2015
<i>Lasiurus frantzii</i>	KP341754	AK11179	Mexico	707	Baird et al. 2015
<i>Lasiurus blossevillii</i>	KP341705	AK13464	Argentina	1140	Baird et al. 2015
<i>Lasiurus blossevillii</i>	KP341707	F44354	Brazil	496	Baird et al. 2015
<i>Lasiurus blossevillii</i>	KP341706	F44348	Brazil	496	Baird et al. 2015
<i>Lasiurus blossevillii</i>	KC747683	MSB63295/NK21290	Bolivia	1135	Málaga et al. 2020
<i>Lasiurus cinereus</i>	KP341711	AK11006	Mexico	1117	Málaga et al. 2020
<i>Lasiurus cinereus</i>	KP341733	NK3627	EE.UU.	1117	Málaga et al. 2020
<i>Lasiurus cinereus</i>	KP341713	AK11014	Mexico	1140	Málaga et al. 2020



Species	GenBank accession no.	Voucher	Country	Cyt- <i>b</i>	Source
<i>Lasiurus cinereus</i>	KP341712	AK11013	Mexico	1117	Málaga et al. 2020
<i>Lasiurus cinereus</i>	KP341718	ASK3520	EE.UU.	1117	Málaga et al. 2020
<i>Lasiurus cinereus</i>	KP341717	ASK1079	EE.UU.	1117	Málaga et al. 2020
<i>Lasiurus cinereus</i>	KP341722	BPBM185245	EE.UU.	1140	Málaga et al. 2020
<i>Lasiurus villosissimus</i>	KP341727	NK11502	Bolivia	1140	Málaga et al. 2020
<i>Lasiurus egregius</i>	KP341746	F54845	Surinam	1140	Málaga et al. 2020
<i>Lasiurus egregius</i>	KP341745	F54554	Guyana	1140	Málaga et al. 2020
<i>Lasiurus insularis</i>	KP341747	TK32049	Cuba	1140	Málaga et al. 2020
<i>Lasiurus intermedius</i>	KP341748	ASK0422	Guatemala	1140	Málaga et al. 2020
<i>Lasiurus ega</i>	KP341744	SP12622	Guatemala	1140	Málaga et al. 2020
<i>Lasiurus ega</i>	KP341741	AK07693	Belize	1140	Málaga et al. 2020
<i>Lasiurus ega</i>	KP341743	NK15304	Bolivia	1140	Málaga et al. 2020
<i>Lasiurus ega</i>	KP341742	NK12302	Bolivia	1140	Málaga et al. 2020
<i>Lasiurus xanthinus</i>	KP341757	NK11103	EE.UU.	1140	Málaga et al. 2020
<i>Myotis velifer</i>	EU680209	MF21044	EE.UU.	982	Málaga et al. 2020
<i>Tadarida brasiliensis</i>	MF135779	UF:31730	Bahamas	1140	Málaga et al. 2020