



# Who's calling? Acoustic identification of Brazilian bats

Adriana Arias-Aguilar<sup>1</sup> · Frederico Hintze<sup>2,3</sup> · Ludmilla M. S. Aguiar<sup>4</sup> · Vincent Ruf-ray<sup>5</sup> · Enrico Bernard<sup>3</sup> · Maria João Ramos Pereira<sup>1,6</sup>

Received: 16 May 2017 / Accepted: 2 April 2018 / Published online: 23 April 2018  
© Mammal Research Institute, Polish Academy of Sciences, Białowieża, Poland 2018

## Abstract

Brazil is a megadiverse country with more than 180 bat species. However, most inventories have been mostly made using mist-net sampling and roost search and due to the lack of bioacoustics studies, the bat fauna is certainly subrepresented and biased. The knowledge on distribution and ecology of Brazilian bats is mainly within the Phyllostomidae. Reliable data on bat echolocation calls is the key to improve the knowledge on the distribution patterns and foraging ecology of the remaining eight bat families present in the country. Our work aims to (i) integrate information on echolocation calls of non-phyllotomids occurring in Brazil; (ii) detect regional changes in the acoustic profile of those species; (iii) identify gaps in knowledge both in terms of species and regions sampled; and (iv) to point out which species are acoustically recognizable in a reliable way. Finally, we present a key to supporting the acoustic identification of non-phyllotomids in Brazil. We compiled publications on echolocation calls of Neotropical bat species occurring in Brazil and summarized qualitative and quantitative information of acoustic parameters used in call descriptions. We considered 93 non-phyllotomid bat species to occur in Brazil of which 65 have been acoustically described but for 28 we found no published information. Information on echolocation calls was retrieved from 47 publications and acquired in 17 countries. The use of bioacoustics can be a fundamental tool to expand the knowledge on Brazilian bats and improve their conservation.

**Keywords** Bat bioacoustics · Chiroptera · Echolocation calls · Insectivorous bats · Neotropical bats

---

Communicated by: Mateusz Ciechanowski

**Electronic supplementary material** The online version of this article (<https://doi.org/10.1007/s13364-018-0367-z>) contains supplementary material, which is available to authorized users.

---

✉ Adriana Arias-Aguilar  
ariasaguilar.a@gmail.com

Frederico Hintze  
fredhintze@gmail.com

Ludmilla M. S. Aguiar  
aguiar.ludmilla@gmail.com

Vincent Ruf-ray  
vruf-ray@biotope.fr

Enrico Bernard  
enricob2@gmail.com

Maria João Ramos Pereira  
maria.joao@ufrgs.br

Universidade Federal do Rio Grande do Sul, Av. Bento Gonçalves, 9500–Campus do Vale, Porto Alegre, RS 91501-970, Brazil

<sup>2</sup> Programa de Pós-Graduação em Biologia Animal, Departamento de Zoologia, Universidade Federal de Pernambuco, Av. Prof. Moraes Rego, 1235, Recife, PE 50670-901, Brazil

<sup>3</sup> Laboratório de Ciência Aplicada à Conservação da Biodiversidade, Departamento de Zoologia, Universidade Federal de Pernambuco, Rua Professor Nelson Chaves s/n, Cidade Universitária, Recife, PE 50670-420, Brazil

<sup>4</sup> Laboratório de Biologia e Conservação de Morcegos, Departamento de Zoologia, Instituto de Ciências Biológicas, Universidade de Brasília, Campus Darcy Ribeiro, Brasília, DF 70910-900, Brazil

<sup>5</sup> Bureau d'Études BIOTOPE, 30 Domaine de Montabo, 97300 Cayenne, French Guiana

<sup>6</sup> Centro de Estudos do Ambiente e do Mar, Universidade de Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal

<sup>1</sup> Programa de Pós-Graduação em Biologia Animal, Laboratório de Evolução, Sistemática e Ecologia de Aves e Mamíferos,

## Introduction

With more than 9.5 million square kilometers, Brazil occupies more than 53% of South America and is considered a megadiverse country (Mittermeier et al. 1998; Lewinsohn and Prado 2005). More than 700 species of mammals are known to occur in Brazil (Paglia et al. 2012) and Chiroptera accounts for nearly 25% of those species. Currently, more than 180 species of bats are known in Brazil (Nogueira et al. 2014; Feijó et al. 2015; Fischer et al. 2015; Gregorin et al. 2016).

However, inventories of bat fauna in Brazil have been mostly made using mist-net sampling and roost search (Willig 1985; Sampaio et al. 2003; Bernard et al. 2011; see Alho et al. 2011 for more details), potentially leaving behind many species of difficult capture or species which require well-defined locations for capture by mist-nets (e.g., drinking sites and commuting corridors) or roosting in unknown or inaccessible sites (Rydell et al. 2002; Kunz and Parsons 2009). Most knowledge on distribution and ecology of Brazilian bats is within the Phyllostomidae which comprises 92 species (Nogueira et al. 2014) while there is still a significant lack of knowledge on the ecology and distribution of the remaining eight families occurring in the country—Emballonuridae, Furipteridae, Molossidae, Mormoopidae, Natalidae, Noctilionidae, Thyropteridae, and Vespertilionidae (Cunto and Bernard 2012).

Phyllostomids are much more easily captured using mist-nets and are known to use a combination of clues to explore the environment, including echolocation, olfaction and vision, while species of the other families use almost exclusively echolocation to navigate and find prey (Kalko and Schnitzler 1998; Schnitzler et al. 2003; Denzinger and Schnitzler 2013). Ecologically, most of these bats fall into the category of aerial foragers (Kalko et al. 2008); in fact, the only exceptions to this pattern are Noctilionids, which are trawling foragers, and the Mormoopid *Pteronotus cf. parnellii*, which is a narrow space-fluttering forager (Denzinger and Schnitzler 2013). Therefore, non-phyllostomid bat species have specialized echolocation calls and are able to easily detect and avoid mist-nets or fly too high to be captured by these (Kalko and Handley 2001; Marques et al. 2015). Due to the lack of bioacoustics studies in Brazil (but see López-Baucells et al. 2016), the bat fauna inventories are certainly subrepresented (e.g., Bernard et al. 2011) and biased (e.g., Cunto and Bernard 2012).

In temperate regions, the use of ultrasound detectors to assess bat diversity has a few decades and is widespread (Ahlén and Baag 1999; Kunz and Parsons 2009). Curiously, although Neotropical bats have been the object of acoustic studies since the mid-1960s (see Grinnell et al. 2016), only recently, researchers started to use bioacoustics as a monitoring tool in that region systematically (Jung and Kalko 2011; Marques et al. 2015; Hintze et al. 2016c). Still, these studies have been restricted to a few localities in some countries: Mexico (e.g., Briones-Salas et al. 2013; Kraker-Castañeda et al. 2013; Orozco-Lugo et al.

2013; Zamora-Gutierrez et al. 2016), Panama (see the works of Elisabeth Kalko and collaborators; Estrada-Villegas et al. 2012; Bader et al. 2015; Gager et al. 2016), Honduras (Espinal and Mora 2015), Costa Rica (e.g., Jung et al. 2014; Arias-Aguilar et al. 2015), French Guiana (e.g., Barataud et al. 2013; Thoisy et al. 2014), Ecuador (e.g., Rivera-Parra and Burneo 2013), Chile (e.g., Rodríguez-San Pedro and Simonetti 2013; Ossa et al. 2015), and Brazil (Borloti et al. 2014; Heer et al. 2015; Marques et al. 2015; Hintze et al. 2016c).

Early descriptions of echolocation bat calls made in the Neotropics were mostly from Central America and Venezuela. Moreover, most used zero-crossing recording systems (aka ANABAT; e.g., O'Farrell and Miller 1997; O'Farrell et al. 1999; Ochoa et al. 2000), which although useful, usually, results in a lack of the resolution of some of the calls' variables and the lack of information about the time amplitude of the calls and multiple harmonics if present (e.g., Fenton et al. 1999, 2001).

Recently, there has been an increase in the description of ultrasound bat calls, with larger datasets and important additions to the knowledge of some bat families such as the Emballonuridae and the Molossidae (Jung et al. 2007; Jung et al. 2014). In 2013, Barataud et al. (2013) published a comprehensive compilation of echolocation calls of French Guiana bats, including species of the Emballonuridae, Furipteridae, Molossidae, Mormoopidae, Natalidae, Noctilionidae, Thyropteridae, and Vespertilionidae. These authors found the identification of the species of those families reasonably reliable using ultrasound recordings while considering the Phyllostomidae acoustically too homogeneous, deeming this family problematic to identify using bat detectors. Descriptions for call belonging to 38 non-phyllostomids bats are available (Jung et al. 2007; Barataud et al. 2013; Jung et al. 2014), but a close comparison with the Brazilian species list indicates that echolocation calls of ca. 60 species of non-phyllostomids remains to be described.

Reliable data on bat echolocation calls is a key to improve the knowledge on the distribution patterns and foraging ecology of non-phyllostomids in Brazil. In addition, changes in Brazilian federal and state laws have led to an increase of demands of bat inventories in Environmental Impact Assessments (EIA) using comprehensive sampling schemes including mist-net captures, roost searches, and acoustic monitoring; the use of acoustic monitoring has been required, or at least suggested in some states (Ramos Pereira et al. 2017) especially for impact assessments of wind farms (Valença and Bernard 2015). Acoustic monitoring is a fundamental tool in EIA in several countries (Government of Alberta Fish and Wildlife Division 2006; Ontario Ministry of Natural Resources 2011; Rodrigues et al. 2015), underlining the need to better know the acoustic profile of Brazilian bats. Moreover, acoustic monitoring can be very useful in the study of spatial-temporal activity and habitat use, niche differentiation, foraging behavior, species distribution, and even the

discovery of cryptic diversity (e.g., Vaughan et al. 1997; Arlettaz et al. 2001; Greif and Siemers 2010; Russo et al. 2012; Thoisy et al. 2014; Hintze et al. 2016b, c).

Therefore, considering the high bat species richness in Brazil, the need for the use of bioacoustics for several purposes in the country—some with legal implications, like incomplete EIA—and the lack of a systematized data bank on the echolocation calls of several Brazilian bats, here we aim to (i) integrate information on echolocation calls of non-phylostomids occurring in Brazil from published works and our own data; (ii) detect acoustic variation and possible regional changes in the acoustic profile of those species; (iii) identify gaps in knowledge both in terms of species and regions sampled; and (iv) to point out which species are acoustically recognizable in a reliable way. Finally, we present a key to supporting the acoustic identification of non-phylostomids in Brazil.

## Methods

We looked for publications containing quantitative information on echolocation call parameters or pulse descriptions for bat species potentially identifiable through their echolocation calls known to occur or potentially occurring in Brazil (Nogueira et al. 2014; Feijó et al. 2015; Fischer et al. 2015; Gregorin et al. 2016) according to their known distribution. All selected publications included information on bat families of the Neotropical region except the Phyllostomidae. We used the Internet search engine Google Scholar. Our search terms included the union of the terms “Chiroptera,” “bat,” and “insectivorous,” with “acoustic identification,” “echolocation calls,” “recordings,” “bioacoustics” and so forth. We used no date range restriction. We retrieved all quantitative (frequency and time parameters) and qualitative information (type and structure) of search echolocation calls as it was reported in the literature, and then we summarized them by species (parameter selection varied per family according to the relevance for identification purposes). For several species, we also included unpublished acoustic information from our own recordings. We used CallViewer18 (Skowronski and Fenton 2008) Auto Detection function using a Hamming window, FFT = 1024, windows length of 1 ms, and a background threshold of 10 dB, to obtain the acoustic parameters of the search phase calls of the echolocation call sequences. All figures (spectrograms and oscillograms) were created with the Avisoft SasLabPro Software (Version 5.2.09, Raimund Specht, Berlin), using a Hamming window, FFT = 512 and overlap 93%, from our own or donated recordings obtained mainly in Brazil.

For each species and study, we retrieved information on year of publication, recording method, and recording location. We collected information on the conservation status of all species using the IUCN (2016) database. Then, we calculated the number of publications per family and region and

counted the number of times each species had been acoustically studied.

While all bat species occurring in the New World do not occur anywhere else, many species occurring in Brazil present wide distribution ranges, ranging from South to North America. For this reason, regions of origin of publications were defined as North, Central, and South America; Caribbean Islands; and their respective main classes of Köppen climate classification: tropical, arid, warm temperate, and cold climate (Peel et al. 2007).

## Acoustic information

We considered 93 non-phylostomid bat species to occur in Brazil. Information on echolocation calls of those species was retrieved from 47 publications ranging between 1997 and 2016 and acquired in 17 countries (Appendix 1). Of the list of 93 species, 65 have been acoustically described but for 28 we found no published information.

Most publications came from tropical region of Central, South (14 publications each), and North America (eight publications), warm temperate North American region (seven publications), Caribbean Islands (five publications), arid North American region (four publications). Accounting the fewest publications were the arid and the warm temperate South American regions (two publications each). Detailed information on the origin and composition of the information used for each bat family is provided below.

### Emballonuridae

Echolocation calls of 15 species have been described in the literature (Table 1). Most described species were *Saccopteryx bilineata*, *Peropteryx macrotis*, and *Saccopteryx leptura*. We did not find any acoustic information for *Diclidurus isabella*, *Peropteryx leucoptera* and *Peropteryx pallidoptera*. For some species information on echolocation calls were given as a complex including *Diclidurus scuttatus/albus* and *Centronycteris maximiliani/centralis*. IUCN (2016) data and (Nogueira et al. 2014) recognize only one species of the genus *Centronycteris* in Brazil: *C. maximiliani*. However, comparisons of our own data collected in the state of Pernambuco with that of Jung et al. (2007), Jung and Kalko (2011), and (Barataud et al. 2013) suggest the existence of *Centronycteris centralis* at least in the northeastern region of the Brazilian territory. For this reason, we decided to consider this species as potentially occurring in Brazil. We also included information from our own recordings of potentially new species of *Saccopteryx* and *Peropteryx*.

Echolocation calls of this family are multi-harmonic, with most energy (peak frequency or frequency of maximum energy (FME)) in the quasi-constant frequency (qCF) part of second harmonic (Table 1 and Fig. 1). Sometimes, but rarely, *Diclidurus*, *Saccopteryx*, and

**Table 1** Summary of echolocation call parameters as retrieved from the literature and our own data for species of the Emballonuridae known to occur, or potentially occurring, in Brazil, with information on region of recording and IUCN status of each species

Species	IUCN status	Region	Structure	Call type	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	CD (ms)	PI (ms)	SI
<i>Cernixx</i> (?)	LC	SA-Tr	Qef/fm down fm up/qef/fm down (qef convex)	mono			40.6 (39–41.3) 41.5 ± 0.2	38.1 ± 1.1	41.6 ± 0.3	5.2 ± 0.4	154.8 ± 56.9	3 17
	<i>Cernixx/cen</i>	SA-Tr	Convex qef up with 2 fm down	single			~40					25
<i>Cencen</i>	LC	NA-Tr CA-Tr	Straight				41.3 ± 0.3 43.5	39.29 ± 0.61	41.63 ± 0.37	6.98 ± 0.73 5.9 ± 1.4	119 ± 10	8 20 21 44
	<i>Conbre</i>	LC	Qef up	low middle high			25.2 ± 1.5 28.1 ± 0.6 31.4 ± 0.4 25 28 31 26 (24.5–26.5) 29.4 (27.5–30) 32.3 (30.5–33.5) 31.36 (29.59–33.67) ~25 ~28 ~30			8.2 ± 2.0 8.2 ± 1.8 8.6 ± 1.6	119 ± 45 100 ± 21 107 ± 38	20 21 44 3
<i>Cytale</i>	LC	CA-Tr SA-Tr SA-Tr	Qef convex	low middle high			29.39 (27.43–31.89) 30.11 (27.09–34.52) ~25 ~28 ~30	29.01 (27.09–31.70)	32.52 (30.39–35.31)	11.97 (9.03–11.97)		38 25
	<i>Dicalb</i>	LC	Convex qef up with 2 fm down	low middle high			35.9 ± 0.4 35.4 (34.5–35.4) ~35			9.8 ± 1.6	154 ± 22/265 ± 68	20 21 3 25
<i>Dicing</i>	LC	CA-Tr	Qef (down)	low middle			23.5 ± 0.3 25.8			9.4 ± 4.7/9.6 ± 5.7 9.7	162 ± 28/317 ± 43 249	20 21
	<i>Dicing</i>	DD	Qef	low			19.6 (18.8–21.8) 21.8 (20.3–23.3) ~19 ~22					3 25
<i>Dicisa</i> <i>Discu/alb</i>	LC	SA-Tr	Qef/fm down	low high			26.5 (24.7–29.4) 30.6 (27.8–31.2) 26 30					3 25
	<i>Perkap</i>	LC	Convex qef down with 2 fm down	low high			31.6 ± 1.6 31.3 (30.7–33) ~29–33			9.6 ± 2.2	170 ± 34/280 ± 31	20 21 3 25
<i>Perleu</i> <i>Permac</i>	LC	NA-Tr-Ar-WT	Convex qef down with 2 fm down	mono single			41.61 ± 2.38 (5.72) 38.6 ± 0.4	37.54 ± 2.30 (6.13) 33.1 ± 1.4	41.87 ± 2.48 (5.92)	7.30 ± 1.30 (17.81) 5.2 ± 0.5		47 40
	<i>Perleu</i>	LC	Cf/start or end shallow down-sweeps									
<i>Perri</i>	NA	NA-Tr	Qef (down)	mono			39.6 ± 1.8 38.9 ± 0.9 38.4 (36.7–39.7) ~37–39	35.56 ± 0.86 39.1 ± 1.8	38.81 ± 0.41 40 ± 1.8	6.14 ± 1.98 8.8 ± 1.2 9.3 ± 1.0	152 ± 59.5 139 ± 14/215 ± 34	8 28 20 21 3 25
	<i>Perri</i>	LC	Convex qef down with 2 fm down (fm up)/qef/fm down	mono single			38.15 (36.56–40.21) 36.33 (32.46–39.52) 39.2 ± 0.7	36.0 (32.46–39.04) 37.2 ± 1.1	40.16 (39.12–42.62) 39.5 ± 0.9	7.29 (4.85–10.69) 8.2 ± 2.3	193.2 ± 123.3	38 3 25

Table 1 (continued)

Species	IUCN status	Region	Structure	Call type	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	CD (ms)	PI (ms)	SI	
<i>Per sp.</i>	NA	SA-Tr	Convex qcf down with 2 fm down	mono			43.5 ± 0.8	40.4 ± 1.1	43.8 ± 0.7	5.9 ± 1.1	98.3 ± 21.8	0	
			Fm up-qcf	mono			41.4 ± 0.5	38.8 ± 0.8	41.6 ± 0.6	7.1 ± 1.4	112.3 ± 24.4	0	
			Fm up-qcf down-fm down										
<i>Rhynch</i>	LC	NA-Tr-Ar-WT CA-Tr	Fm up-qcf down-fm down		98.25 ± 1.16 (1.18)	81.84 ± 4.88 (5.96)	95.79 ± 4.45 (4.65)	81.84 ± 4.88 (5.96)	98.71 ± 1.03 (1.04)	4.38 ± 0.69 (15.75)	60.8 (2.99)	47	
			Straight/up	mono			98.2 ± 2.3		40.2 (0.53)	47.2 (0.06)	4.8 ± 0.9	58 ± 12	21
			Qcf/ fm down Straight/up	mono			95.6 (80.2–98.2)						3
<i>Sacbil</i>	LC	SA-Tr	Qcf/ fm down	mono			89.6 ± 0.5	88.1 ± 0.6	91.0 ± 1.0	5.6 ± 0.3	74.5 ± 50.0	0	
			Straight/up	mono			87.34 (83.53–93.83)	77.0 (73.75–81.49)	94.27 (94.03–94.61)	94.27 (94.03–94.61)	5.89 (5.17–6.70)	29.3 ± 13.7	38
		CI-Tr	a	51.3 ± 0.8	42.2 ± 1.4	52.2 ± 0.9	53.3 ± 1.0	29.3 ± 13.7	38				
			b	100 ± 2.0	74.8 ± 7.6	101.3 ± 1.6	5.9 ± 1.2	25.9 ± 6.7	35				
		NA-Tr-Ar-WT NA-Tr	low	45.38 ± 8.10 (17.85)	45.78 ± 4.60 (10.05)	47.29 ± 5.68 (12.01)	44.10 ± 5.11 (11.59)	48.55 ± 7.33 (15.1)	7.40 ± 1.58 (21.35)	181.1 ± 33.56	47		
			high			44.5 ± 0.7	43.7 ± 0.7	45 ± 0.8	9.2 ± 1.1	180.3 ± 39.07	28		
		CA-Tr	a	46.8 ± 0.8	47.2 ± 0.8	46 ± 0.8	47.2 ± 0.8	47.41	8.8 ± 1.0	180.3 ± 39.07	23		
			b			44.24	47.41				29		
		CA-Tr	low	44.5 ± 1.3	44.5 (0.21)	44.5 (0.21)	46.6 (0.18)	6.7 (0.21)	55.8 (1.85)	29			
			middle	46.8 ± 1.1	46.6 (0.19)	46.6 (0.19)	48.6 (0.17)	6.6 (0.15)	82.5 (3.09)	30			
CA-Tr	low	45.1 ± 2.02	47.0 ± 2.35	47.0 ± 2.35		7.5 ± 1.5	73 ± 17	20 21					
	middle					7.6 ± 1.3	105 ± 25	44					
CA-Tr	alternating	45				8.26 ± 0.22	60.9 ± 5.9	37					
	monotonous	48				8.22 ± 0.18	88.0 ± 4.9						
SA-Tr	low	42.1 (41.2–42.2)				6.43 ± 0.16	93.0 ± 4.4	3					
	high	44.1 (44–44.3)											
SA-Tr	low	43.89 (43.17–44.73)	43.89 (43.17–44.73)	43.73 (42.89–44.28)	46.46 (46.04–46.81)	43.41 (42.59–43.96)	46.81 (46.51–47.08)	7.22 (6.65–7.84)	38				
	high					41.3 ± 1.6	46.3 ± 0.9	8.3 ± 1.9	75.3 ± 11.1	17			
	low	47.9 ± 0.6	47.9 ± 0.6	45.0 ± 0.7	45.0 ± 0.7	49.3 ± 0.7	8.6 ± 1.4	53.5 ± 12.6	25				
	high	~42	~42	~42	~42								
	middle	~45	~45	~45	~45								
CI-Tr	low	42 ± 1.6	42 ± 1.6	32.8 ± 3.2	43.9 ± 1.4	5.2 ± 1.1	56.2 ± 24.2	35					
	middle	52.5 (52.3–54.3)	52.5 (52.3–54.3)	~54	~54				3				
SA-Tr	mono	53.9	53.9	48.35 ± 2.98 (6.16)	47.69 ± 3.77 (7.91)	50.58 ± 2.48 (4.9)	46.66 ± 3.84 (8.23)	51.27 ± 2.50 (4.88)	6.78 ± 2.28 (33.63)	68 ± 24	47		
	single	51.3 ± 1.8	51.3 ± 1.8	54.61 ± 1.8	54.61 ± 1.8				90 ± 28	20 21			
SA-Tr	low	47.4 (46.6–48.7)	47.4 (46.6–48.7)	52.5 ± 5.5	52.5 ± 5.5	49.8 (48.5–50.4)	49.8 (48.5–50.4)				44		
	high	53.31 (53.54–54.25)	53.31 (53.54–54.25)	~48	~48						3		
SA-Tr	low	51.47 (50.97–51.93)	52.5 (51.75–53.20)	51.16 (50.58–51.64)	54.52 (54.27–54.79)	6.76 (6.25–7.32)					38		
	high										25		
SA-Tr	low	48.2 ± 0.6	48.2 ± 0.6	44.5 ± 2.8	49.5 ± 0.6	7.3 ± 1.5	76.6 ± 16.7	0					
	high	50.2 ± 0.3	50.2 ± 0.3	48.2 ± 0.6	51.9 ± 0.8	5.8 ± 0.5	49.6 ± 8.5						
CI-Tr	low	51.1 ± 1.2	51.1 ± 1.2	42.9 ± 1.1 + 3	53.3 ± 1.4	4.9 ± 1.1	66.7 ± 30.2	35					
	high												

SF start frequency, EF end frequency, FME frequency of maximum energy, LF lowest frequency, HF highest frequency, CD call duration, PI pulse interval, SI reference number and species name abbreviations in Appendix 1



*Rhynchonycteris* can produce calls with FME on the fundamental harmonic. With the exception of *Rhynchonycteris naso*, pulses are usually narrow band. Genera *Cormura*, *Diclidurus*, and *Saccopteryx* present frequency alternation but one of the pulses may be omitted at some circumstances, e.g., when foraging close to their roost. The other genera produce monotone frequency calls. Peak frequency, the direction of call modulation, and the presence of alternation are important parameters for species identification (O’Farrell and Miller 1999; Jung et al. 2007; Barataud et al. 2013; see Appendix 2 for further details).

### Furipteridae

*Furipterus horrens* is found from Costa Rica to Peru, the Guianas, Brazil, and Trinidad (Nowak 1994; Simmons et al. 2005; Novaes et al. 2012). Nevertheless, acoustic information on this species was compiled only from four localities of the tropical and warm temperate South American regions (three and one publication, respectively; Table 2 and Fig. 2). However, the authors were not aware of the very high frequencies emitted by this species, so the recorded calls presented some artifacts due to aliasing—to accurately measure the frequency of any signal, the sampling rate of the equipment must be at least double of that frequency; otherwise the signal will be aliased, or false images of the signal will be created as mirror images of the original frequency. This situation is called “aliasing back” or “folding back” and can be seen in Fig. 2, where the highest frequencies of the calls were not registered (Falcão et al. 2015).

Echolocation calls of this species present FME in the fundamental harmonic and above 100 kHz. Pulses are broadband with steep modulation and show an inflection point (Appendix 1).

### Natalidae

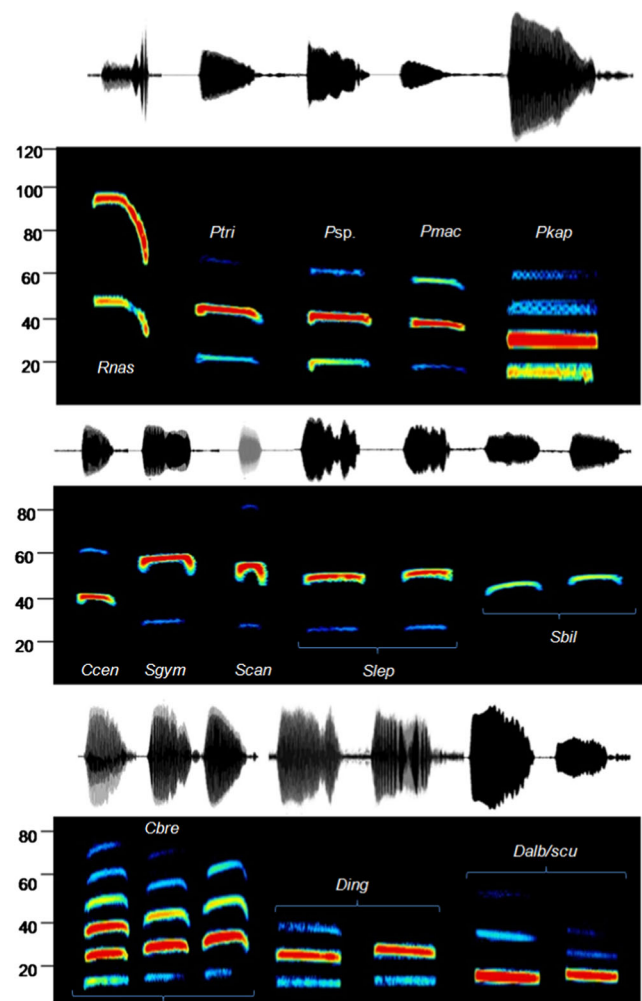
*Natalus macrourus* is the only species of this family reported to occur in Brazil (Garbino and Tejedor 2013; Tejedor and Davalos 2016; Delgado-Jaramillo et al. 2017). Even if widely distributed in the country (Rocha et al. 2013; Delgado-Jaramillo et al. 2017), there is no published acoustic information for this species. Besides, *Natalus tumidirostris* occurs north of the Amazon River (Garbino and Tejedor 2013) and has been acoustically described in French Guiana (Barataud et al. 2013). So we consider this species to potentially occur in Brazil; also, information on the echolocation call parameters of *N. tumidirostris* (Table 2 and Fig. 2) may give some insight on the acoustic profile of *N. macrourus*. In this paper, we present the first spectrogram (Fig. 2) and describe quantitative information on echolocation call parameters for *N. macrourus* recorded in Northeastern Brazil.

Echolocation calls of this family present FME in the second harmonic and above 100 kHz. Pulses are steep modulated with a very short qCF termination (Appendix 2 and Fig. 2).

### Thyropteridae

The genus *Thyroptera* occurs from Mexico to south Brazil (Simmons et al. 2005; Passos et al. 2010). In spite of its wide distribution, acoustic information on the species of the genus is very limited. Echolocation calls are described only for two of the five species occurring in Brazil: *Thyroptera tricolor* (from three localities including French Guiana, Mexico and Ecuador), and *Thyroptera discifera* (from French Guiana) (Table 2 and Fig. 2). Knowledge of the echolocation calls of the remaining species (*Thyroptera devivoi*, *Thyroptera lavalii*, and the recently described *Thyroptera wynneae*) (Velazco et al. 2014) is inexistent.

Echolocation calls of this family can present FME in the fundamental or in the second harmonic. Pulses show elevated initial amplitude and are of short duration (< 4 ms) (Appendix 2).



**Fig. 1** Echolocation calls for species of the Emballonuridae known to occur, or potentially occurring, in Brazil. Call duration and pulse intervals are not scaled. Rnas *Rhynchonycteris naso*, Ptri *Peropteryx trinitatis*, Psp *Peropteryx* sp., Pmac *Peropteryx macrotis*, Pkap *Peropteryx kappleri*, Ccen *Centronycteris centralis*, Sgym *Saccopteryx gymnura*, Scan *Saccopteryx canescens*, Slep *Saccopteryx leptura*, Sbil *Saccopteryx bilineata*, Cbre *Cormura brevirostris*, Ding *Diclidurus ingens*, Dalb/scu *Diclidurus albus/scutatus*

**Table 2** Summary of echolocation call parameters as retrieved from the literature and our own data for species of the Furpteridae, Natalidae and Thyropteridae known to occur, or potentially occurring, in Brazil, with information on region of recording and IUCN status of each species

Species	IUCN	Region	Call type	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	SI	
<i>Furhor</i>	LC	SA-Tr	I				161.3 ± 10.3	128.6 ± 7.6	190.5 ± 3.1	61.9 ± 8.5	3.7 ± 0.5		11	
			II			158.4 ± 12.7	122.8 ± 14.5	191.2 ± 2.7	122.8 ± 14.5	191.2 ± 2.7	68.4 ± 14.9	2.6 ± 0.5	13.1 ± 7.5	
			II	Steep fm Fm		157.2 ± 14.4	135.1 ± 6.6	191.3 ± 1.7	135.1 ± 6.6	191.3 ± 1.7	56.2 ± 6.6	2.3 ± 0.5	15 ± 1.1	
<i>Natmac</i>	NT	SA-WT				130–170	120	150			<1		12	
						120.2 ± 5.8					77.4 ± 29.5	3.5 ± 0.1		3
<i>Thydev</i>	DD	SA-Tr		Qef-fm-qef			53 ± 2.7				2.9 ± 0.5		3	
<i>Thydis</i>	LC	SA-Tr		Fm Fm			112.5 ± 7.3				2.5 ± 0.3			
<i>Thylav</i>	DD						53.09 ± 2.46 (4.63)	43.50 ± 1.87 (4.3)	66.38 ± 2.02 (3.04)	22.88 ± 2.32 (10.14)	2.76 ± 0.37 (3.41)		47	
<i>Thytri</i>	LC	NA-Tr-Ar-WT			66.38 ± 2.02 (3.04)	43.50 ± 1.87 (4.30)	103.12 (98.70–108.83)	91.95 (89.64–96.66)	123.26 (116.93–127.14)	31.31 (25.94–37.19)	1.1 (0.78–1.30)		38	
		SA-Tr			123.26 (116.93–127.14)	91.95 (89.64–96.66)	51 ± 2.2				3.2 ± 0.4		3	
<i>Thywyn</i>	NA													

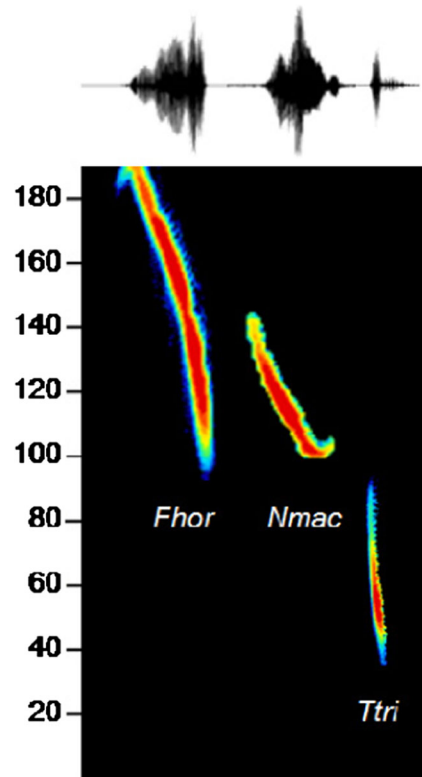
SF start frequency, EF end frequency, FME frequency of maximum energy, LF lowest frequency, HF highest frequency, BW bandwidth, CD call duration, PI pulse interval, SI reference number and species name abbreviations in Appendix 1

**Molossidae**

Twenty-one species occurring in Brazil have been acoustically described in 24 publications mostly originated in the tropical South, North, and Central American regions (Table 3 and Fig. 3). Only one publication including molossids was found for the warm temperate South American region and two for the Caribbean Islands.

*Molossus molossus*, *Molossus rufus*, and *Tadarida brasiliensis* were the most studied within the family (Table 3). We found no information on the echolocation calls of 11 species registered or possibly occurring in Brazil: *Cynomops mastivus*, *Eumops bonariensis*, *Eumops delticus*, *Eumops hansae*, *Eumops maurus*, *Eumops patagonicus*, *Eumops trumbulli*, *Molossus aztecus*, *Molossus pretiosus*, and *Nyctinomops aurispinosus*. If we follow Moras et al. (2016), *Cynomops paranus* described by Barataud et al. (2013) could relate to *Cynomops milleri*. However, if these are not synonyms, then the echolocation calls of *C. milleri* remain non-described.

We considered *C. mastivus*(Moras et al. 2016), *Eumops dabbenei*, *Eumops nanus* (Bartlett et al. 2013) and *Eumops patagonicus* (Bernardi et al. 2009) as full species. Also, we considered *Molossus barnesi* as a synonym of *Molossus coibensis* (Catzefflis et al. 2016).



**Fig. 2** Echolocation calls for species of the Furpteridae, Natalidae, and Thyropteridae known to occur, or potentially occurring, in Brazil. Call duration and pulse intervals are not scaled. Fhor *Furipterus horrens*, Nmac *Natalus macrourus*, Ttri *Tyroptera tricolor*

**Table 3** Summary of echolocation call parameters as retrieved from the literature and our own data for species of the Molossidæ known to occur, or potentially occurring, in Brazil, with information on region of recording and IUCN status of each species

Species	IUCN	Region	Call type	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	SI
<i>Cynabr</i>	LC	SA-Tr	Low	Qef			22.3 (18.8–26.5)				12.5 (9–20)		3
<i>Cyngre/abr</i>		SA-Tr	Middle	Simultaneous qef down		~17	30 (28.2–32)				10.2 (7.7–14.8)		25
<i>Cyngre</i>	LC	CA-Tr	High	Qef down		~21	21–24			7.8±3.1	15.9±2.1	297.2±115.0	20
		CA_SA-Tr	Low		25.2±1.3	17.4±3.6				7.9±4.1	14.8±2.4	190.3±61.0	22
			High		29±1.5	21.1±4.6							
<i>Cymnas</i>	NA												
<i>Cymnil</i>	DD	SA-Tr	Low	Qef		~21	26.5 (23.1–27.8)				15.5 (10.2–18.1)		3
<i>Cyngar</i>		SA-Tr	Middle	Fm down/qef		~24	31.6 (27.8–32.4)				13.9 (10.8–17.3)		25
<i>Cyngar/plan</i>			High	Simultaneous qef down									
<i>Cynplan</i>	LC	CA-Tr	Low	Qef down		~24	25–28						20
		CA_SA-Tr	High	Qef down	28.8±1.3	21.1±2.4				7.6±1.9	16.1±1.9	236.4±79.1	22
			Low	Qef concave/convex	32.9±1.1	24.3±4.6				8.7±4.5	15.9±2.3	165.1±50.8	3
		SA-Tr	Middle	Qef concave/convex			27.8 (24.7–30.7)				13.6 (9.9–17.1)		
			High	Qef down			33.9 (32.4–35.8)				10 (6.9–13.3)		22
<i>Eumaur</i>	LC	CA_SA-Tr	Low	Step fm	32.4±4.3	18.2±1.6				14.3±3.9	20.3±6.9	269.4±68.9	22
			High	Fm qef down	35.8±4.1	21.9±1.6				13.8±4.0	19.3±4.0	215.9±61.0	3
		SA-Tr	Low	Qef concave			18.7 (17.3–21.8)				21.8 (19–27.4)		
			Middle	Fm down/qef			23.3 (20.1–25.7)				19.5 (15.1–23.4)		
			High				26.7 (26.3–27)				18.4 (17.5–19.3)		
<i>Eumbon</i>	LC												
<i>Eumnan</i>		CA_SA-Tr	Low	Fm qef down	27.9±0.1	25.2±0.2				2.8±0.3	15.6±2.4	294.6±32.1	22
<i>Eumolab</i>	LC	CA_SA-Tr	Low	Fm qef down	21.3±1.2	13.7±0.5				7.6±1.1	28.3±2.8	379.9±123.6	22
			High		24.6	15.8				8.9	25.6	332.7	
<i>Eumdel</i>	LC												
<i>Eumgla</i>	LC	CA_SA-Tr	Low	Fm qef down	27.4±3.4	19±0.4				8.4±3.5	16.2±4.5	321.1±102.7	22
			High		29.3±4.2	20.3±0.3				8.9±4.1	16.7±4.5	270.9±92.8	
<i>Eumhan</i>	LC												
<i>Eumnanu</i>	DD												
<i>Eumpat</i>	LC												
<i>Eumper</i>	LC	NA-WT-Sn		Simple sweeps with slight curvature			13.2	9.4	19.8		15.4		18
<i>Eumru</i>													
<i>Eumru/gla/dabhan/mau</i>	LC	NA-WT					7.4 (5.0)	6.8 (4.0)	8.2 (5.9)		57.9 (39.4)	1369 (21.5)	1
<i>Molneg</i>	DD	SA-Tr	Low	Concave qef		~18	<30						25
			High			~22							
		CA_SA-Tr	Low	Fm up qef	32.5±3.3	44.3±1.9				11.8±1.9	10.5±0.9	107.2±3.8	22
			High		38.3±2.4	46.9±0.8				8.5±3.0	9.4±0.4	107±17.1	
			High II	Fm down qef	56.2±2.9	48.9±0.2				7.3±3.0	6.1±1.3	62.2±6.5	
		SA-Tr	Low	Convex qef up		~44							25
			High	Concave qef down		~46							
<i>Moltem</i>	LC	CA_SA-Tr	Low	Fm up qef	42.8±2.6	54.2±1.2				11.4±1.7	8.3±1.2	79.3±5.4	22
			High		45.5±2.4	54.8±1.4				9.3±1.5	7.6±1.1	82.9±3.8	
			High II	Fm down qef	75.9±9.9	55.4±1.5				20.5±10.3	7.2±1.0	55.2±3.9	
		SA-Tr	Low	Fm up	40.4±3.5	50.4±1.5				10.3±3.1	7.8±1.6	97±29.9	15
			High				50.4±1.4narrow/ 45.1±2.6 broad						
			Closed space	Fm up	51.30±0.18	44.06±0.43				8.86±0.41	3.99±0.35	61.76±4.33	31
				Fm down	52.99±0.22	40.08±0.27				26.21±0.34	2.05±0.02	47.48±0.97	



Table 3 (continued)

Species	TUCN	Region	Cull type	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	SI		
<i>Neomata</i>	LC	CA_SA-Tr	Hand release	Fm up	43.98±0.20	51.74±0.14	49.38±0.15	43.98±0.20	51.74±0.14	7.76±0.12	4.11±0.11	118.63±4.52	25		
			Low	Fm down	43.31±0.51	58.82±0.63	45.62±0.81	43.31±0.51	58.82±0.63	16.51±0.45	3.23±0.15	99.66±4.69			
			High	Convex qcf up	~54										
				Concave qcf down	~55										
			Low	Fm up-qcf	46.5±2.1	39.3±2.4	54.7±0.9	39.3±2.4	52.1±1.2	12.8±2.3	8.1±0.7	73.8±10.1		°	
<i>Neomata</i>	LC	SA-Tr	High (type I)	Fmd-qcfd	32.6±1.7	28.2±1.3	54.7±0.9	52.7±0.6	85.0±7.1	32.2±7.6	8.2±0.4	48.3±4.4	22		
			High (type II)	(Fm) qcf down	36.9±0.9	33.6±1.2	32.3±1.3	27.7±0.9	34.3±0.9	4.3±0.7	12.2±2.9	160.9±40.5			
			High	Shallow fm or fm up-qcf						3.4±1.2	11.9±3.6	105.1±22.5			
			Low	Fm down - qcf down			35.8±1.8	34.1±1.5	37.9±1.7	3.9±0.5	6.5±0.8	10.0±0.9		°	
<i>Molaz</i>	LC	SA-Tr	Low	Qcf concave/convex	32.4 (29.4–41.5)		32.4 (29.4–41.5)		12.8 (5.8–16.9)			3			
			Middle		29.8±1.9	34.9 (35.3–48.7)		11.5 (5.5–15.3)				13			
<i>Molbar</i>	LC	CA-Tr	I		35.4±1.3	29.8±1.9			5.6±1.3		76.2±23.6	20			
			II		39.7±2.1	35±1.8	2830/33		4.7±1.2	0.3±0.3	153.8±58.9				
<i>Molcur</i>	LC	CA-SA-Tr	Low	Qcf down	29.7±1.3	24.4±2.2			4.3±3.3		13.9±1.7	205.8±57.9	22		
			Middle		32.9±1.6	28.2±2.7			4.4±3.0		14.1±1.8	134.9±31.5			
			High		35.1±0.7	30.3±2.0			3.2±4.3		14.4±1.9	126.4±34.3			
					37.45±4.55 (12.15)	34.95±4.03 (11.53)	38.38±4.59 (11.96)	34.71±4.09 (11.78)	38.93±4.57 (11.74)	4.22±1.55 (36.73)	8.72±2.49 (28.56)	9.54±2.06		47	
<i>Molmol</i>	LC	NA-Tr-Ar-WT	Low	Qcf down	33.65±2.82	33.9±4.52	35/39/42	30.3±4.76	33.9±4.52		9.3±2.97	8			
			Middle		39.1±3.6	34.4±3.8							30		
<i>Molpre</i>	LC	CA-SA-Tr	I		42.8±2.9	39.1±3.0			4.7±2.0		0.6±0.3	75.4±24.6	13		
			II		35.6±0.9	33.5±1.2			3.8±1.4		0.6±0.3	117.6±44.5			
			Middle		39.1±0.9	36.8±1.0			2.2±0.8		10.4±1.4	143.1±25.4			
			High		42.8±0.8	39.8±1.2			2.2±0.6		10.2±1.3	109.2±44.7			
			Low						3±1.2		10.4±2.2	82.8±12.2			
			Middle						37.5 (32.4–38.4)		10.5 (7.3–14)			3	
			High						41.4 (38.4–42.7)		10 (6.7–12.9)			8	
									44.3 (41.3–44.3)		8.6 (7.9–9.2)			20	
									38.16 (35.72–40.76)		12.01 (10.50–13.43)			38	
									37.59 (35.02–40.42)		3.17 (2.41–4.09)			7	
<i>Moltrif</i>	LC	CI-Tr	1	Narrow bandwidth	42.445	45.743	42.445	31.601	38.78 (36.64–41.36)	3.17 (2.41–4.09)	5.7		28		
			2	Slightly modulated	42.376	45.934	42.376	32.201	45.743	6.2					
			3	Modulated	42.69	43.283	42.69	30.507	43.283	5.2					
			Low	Fm up convex	~33–35										
			Middle	qcf down	~35–40										
			High		~40–45										
			Low	Qcf down or qcf convex	33.0±0.6	29.9±0.8	37.1±1.9	33.6±2.1	39.7±6.3	6.0±4.9	3.9±1.5	10.1±1.3		175.5±56.4	°
			Middle		47±6.0	22.7±2.6	35.2±3.9	4.2±2.2	50.3±5.1	9.8±2.5	4.8±1.2	40.7±16.5		35	
			A	Qcf (concave/convex)/fm	36.5±2.9	32.5±3.8	41.6±4.6	5.8±5.8	9.3±2.6	92.8±37.6				4	
			B	Qcf or fm	44.4±7.1	38.7±4.2									
<i>Moltrif</i>	LC	NA-Tr	Low		29.4±1.9	29.9±1.8	29.4±1.9	28.1±2.5	29.9±1.8		13.2±3.3	263.4±82.5	23		
			High		33.0±1.5	33.6±1.7	33.0±1.5	32.0±1.7	33.6±1.7	13.4±3.6	344.6±131.9				
					28.8	33.61	28.8	25.16±4.05	29.7±3.74		11.08±3.55	8			

Table 3 (continued)

Species	TUCN	Region	Call type	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	SI	
<i>Molossini/cur/huf</i>	LC	NA-Tr-Ar-WT			31.48±3.95 (12.55)	29.05±2.94 (10.12)	31.89±3.91 (12.26)	28.79±2.88 (10)	32.28±3.82 (11.83)	3.49±2.32 (66.48)	9.73±4.24 (43.58)		47	
		CA-Tr		Qcf (down)			25	27.2±4.43	30.8±4.29		11.6±3.68		30	
	LC	CA_SA-Tr	Low	Qcf down	26.3±0.4	24.7±0.6	< 35			1.6±0.6	12.7±0.7	409±116.3	22	
		SA-Tr	High	Qcf down	27.8±0.4	25.7±0.5	26.5 (24.4–30.7)			2±0.5	12.9±1.2	343.7±131.0	2	
	LC	SA-Tr	Low	Qcf			30.7 (29.4–33.7)				17.3 (8.6–20.8)		3	
			Middle	Qcf			35.2 (34.3–38.2)				15.3 (9.1–17.7)			
	LC	SA-Tr	High	Qcf (steep fm)	27.44 (26.35–28.53)	24.76 (24.08–25.59)	26.13 (25.36–26.98)	24.45 (23.90–25.19)	27.69 (26.86–28.73)	3.16 (2.74–3.57)	16.2 (10.4–24.2)	13.0 (11.88–14.27)	259.5±114.6	38
			Low	Qcf down or qcf convex			24.7±1.1	20.2±1.3	27.2±0.8	7.0±1.2		16.4±1.0		0
	LC	SA-Tr	Middle	Qcf or fm-qcf			28.5±0.9	24.0±2.9	30.5±1.1	6.5±2.6	16.4±1.5	148.7±54.2		
			High	down			32.7±0.7	28.7±0.2	42.0±0.4	13.3±0.2	23.0±1.3	83.8±7.3		
LC	SA-Tr	Low	Fm up convex			40.44±5.09	37.26±4.84	41.41±5.16	4.15±1.62		3.6±1.2		41	
		Middle	qcf down			25–30							25	
LC	SA-Tr	High	qcf down			30–35								
		Low	Qcf down or qcf convex			35–40								
LC	SA-Tr	Middle	Qcf down or qcf convex			29.5±1.1	26.0±1.4	30.4±0.8	4.4±1.0	7.6±1.3	121.4±3.1		0	
		High	qcf convex			33.3±0.5	31.3±0.8	34.4±0.2	3.1±0.8	7.4±0.3	91.5±14.5			
LC	SA-Tr	Low	Qcf convex			35.7±0.7	32.4±0.8	36.1±0.4	3.7±0.7	6.6±0.6	94.9±9.8			
		High				26.4±2.5	25.1±2.0	29.7±3.1	19.15±0.85		12.5±2.1	189.5±19.5	28	
LC	SA-Tr	Low	(Fm) qcf down			25.68±3.35 (13.05)	17.67±0.67	41.03±4.19 (10.21)	23.07±3.91 (16.95)		14.49±1.50		8	
		Middle				24–26					4.85±1.40 (28.87)		47	
LC	SA-Tr	High				26.7±1.3	23.6±0.9			2.4±0.9	12.5±1.4	393.7±116.7	22	
		Low				28.7±1.1	24.2±0.9			4.6±1.6	12.3±1.2	292.9±82.3	20	
LC	SA-Tr	Middle				32.4±1.3	24.9±1.2			7.5±2.0	12.7±2.9	213.6±59.6	22	
		High				12 (12.8)	11.3 (11.3)	13 (16.2)			18.6 (23.5)	1203 (75.9)	1	
LC	SA-Tr	Low	(Fm) qcf down			28.59±4.52 (15.81)	13.79±4.26 (30.90)	22.34±2.76 (12.35)	13.79±4.26 (30.89)	14.86±3.38 (22.75)	7.92±1.40 (17.68)	284.7	47	
		Middle				28.8	16.7			12	13.3		22	
LC	SA-Tr	High	Fm up			22.89±1.38 (6.03)	26.94±1.45 (5.38)	26.03±1.33 (5.11)	22.82±1.32 (5.78)	4.94±1.40 (28.34)	47.66±24.30 (50.99)		47	
		Low	Fm up qcf/ fm down qcf			23.0±0.72	25.6±0.47	24.7±0.57		2.7±0.56	20.6±3.90		16	
LC	SA-Tr	Middle	Fm up qcf			25.8±0.8	28±0.7			2.2±0.7	17.8±3.3	276.9±91.2	22	
		High	Fm down qcf			35.7±6.5	30.4±1.1			8.1±0.7	17.1±7.8	158.9±88.8	3	
LC	SA-Tr	Middle	Qcf concave			~28					14.1 (13.2–14.8)		25	
		Low	Qcf up			35.4 (33.7–36.7)	29.3 (26.3–32.3)				21.2 (17.4–35)		25	
LC	SA-Tr	High	Concave qcf up			~30							38	
		Low	qcf down			24.79 (23.16–29.05)	29.12 (27.1–30.40)	29.65 (28.19–30.03)	24.38 (23.12–25.68)	30.36 (29.40–32.32)	5.8 (4.71–6.98)	53.63 (26.24–75.91)	209.5±21.9	22
LC	SA-Tr	Middle	Fm up qcf			32.7±1.3	34.7±1.3			2±0.5	11.6±0.6	105.7±0.0	25	
		High	Fm down qcf			47±0.0	37.8±0.0			9.2±0.0	8.3±0.0		25	
LC	SA-Tr	Middle	Concave qcf up			~34							38	
		Low	qcf down			34.1±1.2	32.6±1.3			3.2±1.4	14.3±2.9	227.4±121.0	0	
LC	SA-Tr	High	Qcf up			38.6±1.6	34.5±2.1			9.4±0.5	19.6±1.1	94.5±10.7	18	
		Low	Fm-qcf down			28	24.1			11.5	11.5		14	
LC	SA-Tr	Middle				24.5±1.6	22.7±1.5			4.3±2.4	12.8±1.1		14	
		High				24.8 (23.9–25.2)	24.1 (22.8–25.4)			2.73 (1.68–3.13)	14.2 (13.8–16.0)		36	
LC	SA-Tr	Low				24.1 (22.8–25.4)			5.0 (3.06–5.59)	12.3 (12.1–14.5)			36	
		High												

Table 3 (continued)

Species	TUCN	Region	Call type	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	SI
		NA-Tr			37.7 ± 0.01	24.4 ± 0.06	25.0 (24.9–26.8)	26.3 (13.6)	30.3 (17.5)	2.49 (1.52–2.92)	13.6 (13.2–15.0)	239.7(38.3)	1
		NA-Tr-Ar-WT			46.81 ± 5.42 (11.58)	26.09 ± 2.47 (9.47)	27.5 (13.8)	27.32 ± 0.97	34.04 ± 3.16		13.7 (16.2)		8
		CA SA-Tr	Low	(Fm) qcf down	27.6 ± 3.0	24.4 ± 1.3	28.1 ± 0.01				8.3 ± 0.03	109	32
		SA-Ar			28.03 ± 0.59	21.05 ± 0.25	32.61 ± 3.73 (11.44)	26.09 ± 2.47 (9.47)	46.83 ± 5.41 (11.55)	20.74 ± 5.04 (24.3)	7.20 ± 1.93 (26.81)		47
		Cl-Tr		Concave qcf	28.9 ± 2.7	26.1 ± 2.0	24.31 ± 0.32	22.75 ± 0.25	27.41 ± 0.50	3.2 ± 2.5	13.7 ± 1.5	273.1 ± 55.5	22
		SA-Tr	Low	Concave qcf		~18	27.3 ± 2.2			4.65 ± 0.37	13.62 ± 0.29	286.90 ± 18.92	39
			High			~22	<30			2.8 ± 1.5	12.1 ± 1.8	267.7 ± 116.9	4
													25

SF start frequency, EF end frequency, FME frequency of maximum energy, LF lowest frequency, HF highest frequency, BW bandwidth, CD call duration, PI pulse interval, SI reference number and species name abbreviations in Appendix 1

Echolocation calls of molossids have FME at fundamental harmonic with long, shallow-modulated signals emitted at rather low frequencies (Jung et al. 2014). Usually, calls show irregular frequency alternation, variable amplitude, and great plasticity.

## Mormoopidae

Acoustic information of the species known to occur in Brazil was retrieved from 19 publications (Table 4 and Fig. 4). *Pteronotus* cf. *parnellii* was the most studied species (21 publications). However, recent studies (Clare et al. 2013; Thoisy et al. 2014) had shown that *P. parnellii* is very likely to be a complex of species, which will require further examination of the calls belonging to these taxa. *Pteronotus davyi*, *Pteronotus personatus*, and *Pteronotus gymnotus* accounted 12, 10, and five publications, respectively. To the present, *P. davyi* has not been recorded in the Brazilian territory; nevertheless, considering its wide distribution, its occurrence in neighboring regions, and knowledge on its ecology, we decided to consider it as potentially occurring in Brazil.

Echolocation calls of mormopids are very distinguishable: the calls are usually multi-harmonic and FME is in the second harmonic; calls are shaped like a “lazy-z” (*P. personatus* and *P. davyi*), though sometimes not fully evident (*P. gymnotus*); *P. cf. parnellii* presents high duty cycle echolocation (> 25%) and, frequently, its pulses show a long constant frequency (CF) section (> 20 ms) (O’Farrell and Miller, 1999) (Fig. 4, Appendix 2).

## Noctilionidae

The two species of this family, *Noctilio albiventris* and *Noctilio leporinus* are widely distributed, occurring from southern Mexico to southern South America (Barquez et al. 2015a, 2015b); nevertheless, acoustic information was limited to a few localities of the tropical regions of North, Central, and South America and West Indies (Table 5 and Fig. 5). Echolocation calls of this family are very characteristic showing FME in the fundamental harmonic, a qCF/FM structure with energy uniformly distributed along the pulse or at the end of the FM component; the bandwidth of the FM component is usually > 10 kHz (Fig. 5; Appendix 2).

## Vespertilionidae

Acoustic information of 19 species was compiled from 24 references (Table 6 and Fig. 6).

We were not able to retrieve any acoustic information on *Eptesicus andinus*, *Eptesicus taddeii*, *Histiotus alienus*, *Lasiurus ebenus*, *Lasiurus salinae*, *Myotis dinellii*, *Myotis izecksohni*, and *Myotis simus*. For *Lasiurus castaneus*, there

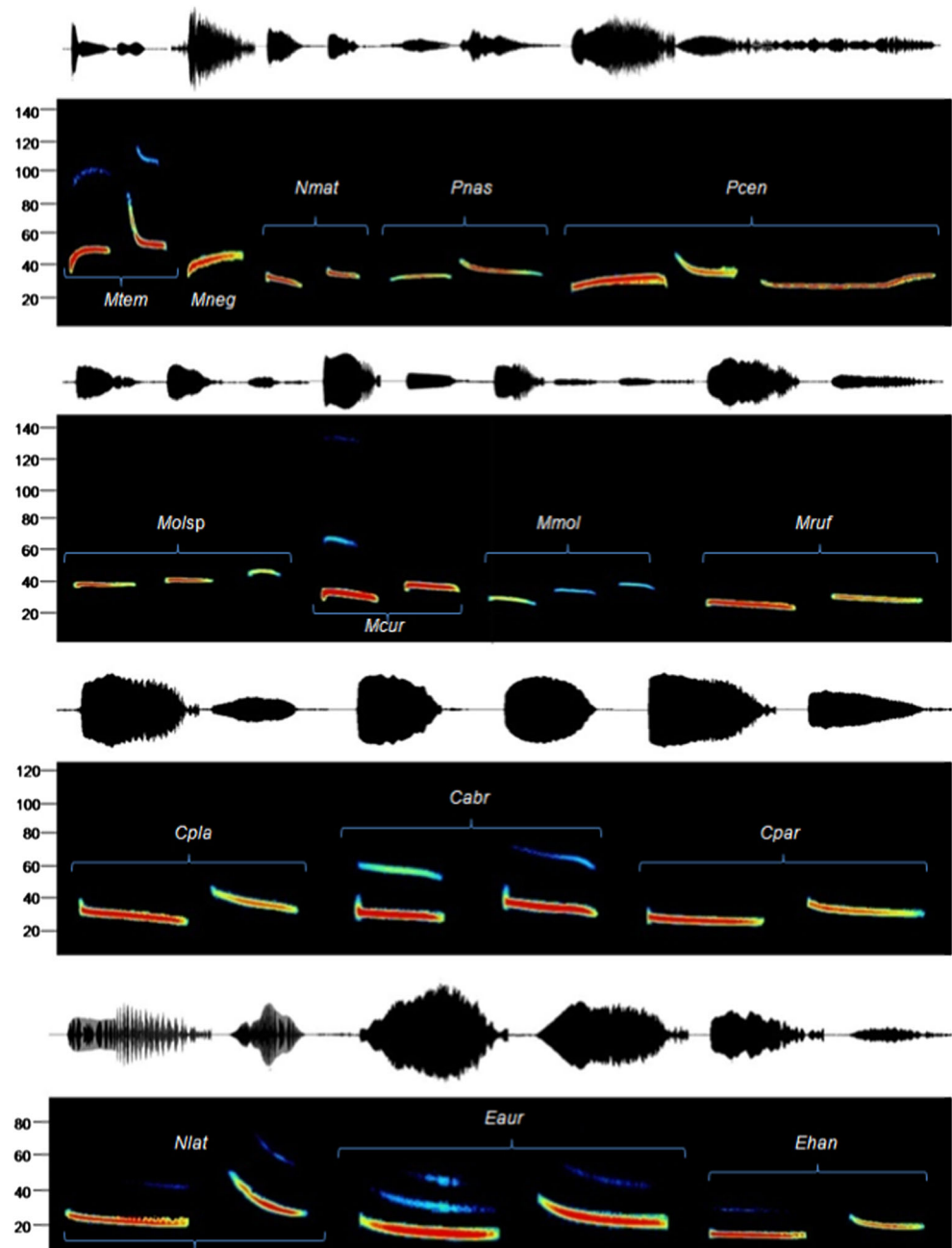
is some information but as a complex with *Lasiurus egregious* (López-Baucells et al. 2016). Here we present information on echolocation calls of *Histiotus diaphanopterus* (E. Barbier personal communication, 2016), a species recently described for Brazil (Feijó et al. 2015) and included information for *Myotis lavalii* and *Rhogeessa hussoni* from our own recordings.

Echolocation calls of this family show FME in the fundamental harmonic; pulse structure usually shows a broadband downward FM component and a downward qCF termination. FME and Fmin are important call parameters for species recognition (Appendix 2).

## Acoustic identification key

Based on the data we compiled for previously presented eight families and our own data, we provide here a key supporting the acoustic identification of Brazilian bats (Appendix 2). This key was made using several qualitative and quantitative acoustic parameters (e.g., call structure, harmonics, call frequencies, call duration, and duty-cycle) that allow identifying 62 taxa, including two Phyllostomidae species (*Lonchorhina aurita* and *Lonchorhina inusitata*). Working with spectrograms, oscillograms, and power spectrum on bioacoustics software, this key

**Fig. 3** Echolocation calls for species of Molossidae known to occur, or potentially occurring, in Brazil. Call duration and pulse intervals are not scaled. Mtem *Molossops temminckii*, Mneg *Molossops neglectus*, Nmat *Neoplantomys mattogrossensis*, Pnas *Promops nasutus*, Pcen *Promops centralis*, Molsp *Molossus* sp., Mcur *Molossus currentium*, Mmol *Molossus molossus*, Mruf *Molossus rufus*, Cpla *Cynomops planirostris*, Cabr *Cynomops abrasus*, Cpar *Cynomops paranus*, Nlat *Nyctinomops laticaudatus*, Eaur *Eumops auripendulus*, Ehan *Eumops hansae*



**Table 4** Summary of echolocation call parameters as retrieved from the literature and our own data for species of the Mormoopidae known to occur, or potentially occurring, in Brazil, with information on region of recording and IUCN status of each species

Species	IUCN	Region	Call type	Structure	SF (kHz)	EF (kHz)	Charact. F	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	DC (%)	SI				
<i>Pteridav</i>	LC	NA-Tr		Cf fm qef	71.5 ± 0.05	59.4 ± 0.03		73.3 ± 0.03	68.1 ± 1.8	69.6 ± 1.2		6.4 ± 0.02	64.8		32				
								69.1 ± 1.2		6.8 ± 0.9				66.8 ± 20.1		28			
								73.6 ± 2.0		4.9 ± 0.6		16.2 ± 1.8					43		
										58.88		59.64 ± 1.06	72.96 ± 1.32			5.92 ± 0.99		8	
										69.8 ± 0.7		57.44	69.23		8.2 ± 0.5			23	
																		17.1	40
																			47
																			29
																			19
																			3
<i>Pterom</i>	LC	NA-Tr-Ar-WT	H2	Cf fm down qef	71.5 ± 0.2			68.0 ± 0.8/58.0 ± 0.9	58.00 ± 2.0 (8.27)	71.24 ± 2.52 (3.54)	12.92 ± 1.60 (12.38)	5.84 ± 1.11 (19.01)	62.2(3.38)		29				
																	19		
																		3	
																		4	
																		46	
																		47	
																		44	
																		20	
																		3	
																		25	
<i>Pterop</i>	LC	Na-Tr		Cf fm qef	82.2 ± 0.05	67.6 ± 0.02		53.1 ± 2.7	48.4 ± 1.5	60.6 ± 1.0	12.3 ± 1.7	5.3 ± 0.6	84.9 ± 53.0	7.5 ± 3.2	32				
																	27		
																		28	
																		43	
																		8	
																		47	
																		29	
																		20	
																		3	
																		25	
<i>Ptemes G1</i>	LC (?)	NA-Tr	H2	Fm up cf. fm down	61.3 ± 1.8	55.7 ± 2.8		68.7 ± 3.1	65.3 ± 2.4	80.0 ± 1.6	14.7 ± 1.6	5.1 ± 0.8	55.4 ± 28.0	9.4 ± 2.5	32				
																	40		
																		28	
																		43	
																		8	
																		23	
																		47	
																		29	
																		20	
																		3	



Table 4 (continued)

Species	IUCN	Region	Call type	Structure	SF (kHz)	EF (kHz)	Charact. F	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	DC (%)	SI			
<i>Pteropus</i> G2		SA-Tr	group 1 62 kHz					62.1 ± 1.91								9		
			Cf fm down					60									20	
			Cf fm down						58.4 ± 0.7									3
			phonic type 59						59.2 ± 0.68									45
			phonic type 59						~60									25
<i>Pteropus</i> G3-4		CI-Tr	60 kHz	Fm up cf. fm down				58.9 ± 0.39								9		
			group 2 59 kHz														9	
			FH		60.6 ± 0.08	48.05 ± 0.61		60 ± 0.17	59.61 ± 0.16	60.23 ± 0.16	0.62 ± 0.05	21.23 ± 0.87					26	
			H2		28	23		58.2 ± 0.7	46.3 ± 1.9	60.2 ± 0.8		21.0 ± 5.5			25.0 ± 15.6		35	
			phonic type 53		56.2 ± 3.9	46.8 ± 1.6		31.2				14.5			38		46	
<i>Pteropus</i> G3-4		SA-Tr	60 kHz	Fm up cf. fm down				61.3 ± 0.8								3		
			group 3-4 53-54 kHz	Cf fm down				52.6 ± 0.5						22.0 ± 5.7	56 ± 20		3	
			55 kHz															45
			kHz															9
			55 kHz															9
<i>Pteropus</i>		SA-Tr	Fm up cf. fm down (Fm up-) cf-fmd				~55									25		
																	25	
																	25	
<i>Pteropus</i>		SA-Tr					93	54.2	93.8	39.6	117.55				38			
					54.2	87.8		53.9 ± 3.4	46.7 ± 2.3	57.2 ± 0.5	10.6 ± 2.4	15.8 ± 4.8	47.4 ± 37.7	31.1 ± 10.9	°			

SF start frequency, EF end frequency, Charact F characteristic frequency, FME frequency of maximum energy, LF lowest frequency, HF highest frequency, BW bandwidth, CD call duration, PI pulse interval, DC duty cycle, SI reference number and species name abbreviations in Appendix 1

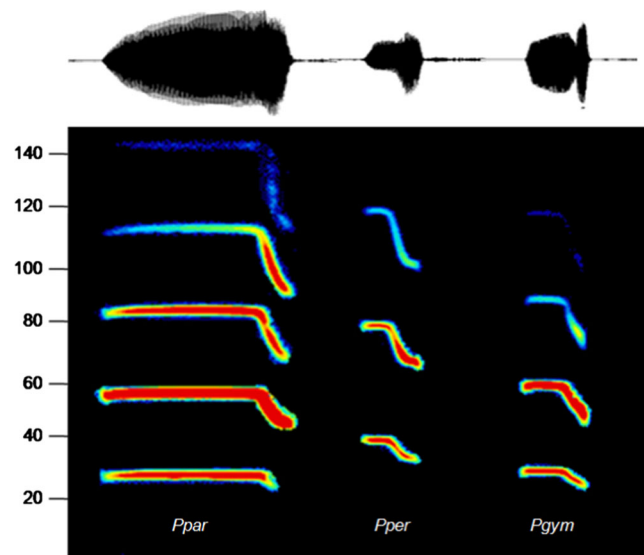
allows identifying at the species level in some cases. Despite the new additions performed in this work, yet this key does not embrace all the species occurring in Brazil. We emphasize that the goal of this key is not to exclude bibliographic search but to be one more tool to aid in the acoustic identification of Brazilian bats.

### Acoustic variability in echolocation calls

Considering that most of the acoustic information of the species was retrieved from outside Brazil, it is important to assess if identifications of some species could be affected by regional variation of their echolocation calls (Jiang et al. 2015) or by another sources of variation. Therefore, when available, we compared the parameters from calls obtained in Brazil with calls from other regions, in order to detect possible regional differences. For the majority of the species, we were only able to compare the regional variation in FME, the most commonly used acoustic parameter and, at least from our compilation, apparently less susceptible to biases due to recording method and technology. However, the number of individual pulses evaluated per species was highly variable across studies (from 3 to 1295), so the average values presented by the authors have variable accuracy and precision. For this reason, we only describe general patterns in acoustic variation in FME within some of the best-studied families and species. If the detected differences are due to low taxonomic resolution, biased data, or to some local adaptation (geographic variation) is still to be determined. In fact, we must underline that there may be erroneous identifications in several groups, as the taxonomic resolution of many species is still far from accomplished.

We found great acoustic variability in 10 bat species: *R. naso*, *S. bilineata*, *S. leptura*, *F. horrens*, *M. rufus*, *Lasiurus blossevillii*, *Lasiurus cinereus*, *Lasiurus ega*, *Myotis nigricans* and *Myotis riparius* (see Tables 1, 2, 3, 4, 5, and 6). For example, *L. blossevillii* showed a significant variation in FME across North, Central, and South America and *M. riparius* FME ranged from 55 to 66.56 kHz solely in South America (Table 6). Also, *M. rufus* showed higher FME values in South America; there is significant overlap in FME between *M. rufus* and *M. currentium*, which may be due to erroneous identification as one of the species or more likely, due to their high variability on echolocation calls related to the flying environment. Finally, though we only retrieved four studies for North America regarding *L. cinereus*, they showed clear differences in the FME recorded for the species (20.8; 35.47 kHz), which perhaps could be related to different recording conditions (hand release recording or degree of vegetation clutter).

The review of Jiang et al. (2015) revealed that geographic variation of bat echolocation calls is not uncommon, averaging 5 to 10 kHz differences in peak frequency. Differences above 10 kHz in FME within the same species are, according to those authors, due to morphological differences among



**Fig. 4** Echolocation calls for species of Mormoopidae known to occur, or potentially occurring, in Brazil. Call duration and pulse intervals are not scaled. Ppar *Pteronotus cf. parnellii*, Pper *Pteronotus personatus*, Pgym *Pteronotus gymnotus*

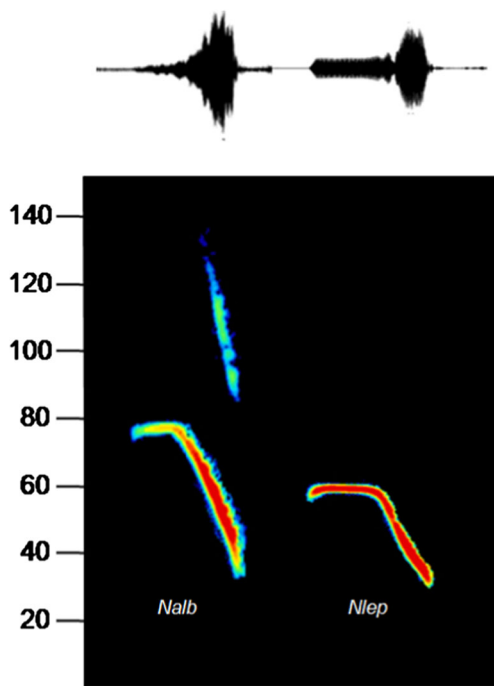
subspecies across large spatial scales. Also, they suggest that geographic variation in echolocation pulses of bats may be caused by genetic drift, cultural drift, and ecological, sexual, and social selection. Changes in echolocation pulses may thus reflect previous changes in other aspects of the phenotype (e.g., morphology) and local adaptation (changes in prey preferences), which may lead to reproductive isolation, eventually to divergence among populations of the same species, and ultimately to species subdivision.

In bats and other small-bodied mammals, species with extremely large distribution ranges have historically been split into complexes of cryptic species. The genus *Miniopterus* is an example: Until recently, *M. schreibersii* was considered to be a cosmopolitan species with a near-global distribution (Simmons et al. 2005). However, several studies, from molecular to ecological modeling (Appleton et al. 2004; Miller-Butterworth et al. 2005; Furman et al. 2010a, 2010b) demonstrated that *M. schreibersii* is a complex of several species distributed across Africa, Europe, Asia, and Oceania, with at least 18 clades occurring solely in Madagascar (Christidis et al. 2014). We hypothesize that for some Neotropical species, this is also the case. Indeed, many of the presently accepted species for this region show very large distribution ranges, and recent works have already revealed complexes of species within the same taxon [e.g., *Pteronotus parnellii* (López-Wilchis et al. 2016), genus *Sturnira* (Velazco and Patterson 2013), *Plathyrrhinus* (Velazco 2005), *Saccopteryx* and *Cormura* (Clare et al. 2007)]. Acoustic variation within the *P. parnellii* species complex supports this idea (Table 4). Therefore, the differences we found for some species (*R. naso*, *S. bilineata*,

**Table 5** Summary of echolocation call parameters as retrieved from the literature and our own data for the two species of the Noctilionidae, with information on region of recording and IUCN status of each species

Species	IUCN	Region	Call type	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	DC (%)	SI		
<i>Noctulb</i>	LC	CA-Tr		Cf-fm			70							44		
				down											20	
				Broad band	66.34 (65.80–67.07)	44.83 (42–49.18)	52.47 (48.37–57.28)	44.83 (42–49.18)	67.51 (67.04–68.11)	22.68 (18.59–25.42)	9.99 (9.12–10.73)					38
				Cf-fm			69.7 (68–75.7)									29.5
<i>Noctlep</i>	LC	CA-Tr		Narrow band			71 (66.7–74.7)			16 (9.7–42)				67.4		
				down											25	
				Cf-fm	68–76											
				Cf-fmd	~74	38.9±4.9	48.6±3.9	38.9±4.9	74.1±1.4	35.3±4.6	7.8±1.1	62.7±36.8	13.8±7.6			44
<i>Noctulb</i>	LC	CA-Tr		Cf-fm			65							20		
				down											20	
				Broad band	50.79±5.09 (10.02)	23.55±3.44 (14.61)	31.03±3.45 (11.12)	23.52±3.42 (14.54)	50.96±5.22 (10.24)	27.43±4.75 (17.32)	8.41±3.44 (40.9)					30
				Cf-fm												47
<i>Noctulb</i>	NA-Tr	Ar-WT		down				40.7±10.54	51.2±5.06		7.0±3.62			8		
				Broad band			57.6 (53.4–60.6)	29.63	57.14	33.6 (22–39.1)					3	
				Narrow band			57.6 (56.3–59.3)			13 (8.3–17.6)						70.2
				Cf-fm												38
<i>Noctulb</i>	LC	CA-Tr		Cf fm	50.66 (48.11–53.11)	27.63 (26.58–28.58)	34.61 (32.52–37.24)	27.61 (26.57–28.57)	50.68 (48.16–53.12)	23.07 (20.88–25.15)	12.72 (11.73–13.79)			25		
				down												
				Cf fmd	~60	38.6±7.2	48.4±5.4	34.1±5.6	60.2±0.6	26.1±5.4	10.7±2.4	66.9±100.7	24.7±10.4			4
				Cf/fm	53.8±7.7	38.6±7.2	52.2±7.7			15.6±5.5	10.7±2.0	98.3±48.1				4
<i>Noctulb</i>	LC	CA-Tr		Broad band	54.4±7.2	22.6±4.9	39.3±8.6			32.0±5.4	11.8±2.2	65.3±23.7				
				down												

SF start frequency, EF end frequency, FME frequency of maximum energy, LF lowest frequency, HF highest frequency, CD call duration, PI pulse interval, DC duty cycle, SI reference number and species name abbreviations in Appendix 1



**Fig. 5** Echolocation calls for species of Noctilionidae known to occur, or potentially occurring, in Brazil. Call duration and pulse intervals are not scaled. Nalb *Noctilio albiventris*, Nlep *Noctilio leporinus*

*S. leptura*, *F. horrens*, *M. rufus*, *L. blossevillii*, *L. cinereus*, *L. ega*, *M. nigricans* and *M. riparius*) make them priority candidates for investigating the existence of geographical variation, the actual magnitude of such variation, and ultimately to detect potential cryptic complexes of species suggested by significant acoustic variation.

## Current status and perspectives

We compiled and presented detailed data for echolocation calls for nearly two-thirds of non-phyllotomid bats occurring in Brazil, including 67 species of Emballonuridae, Furipteridae, Molossidae, Mormoopidae, Natalidae, Noctilionidae, Thyropteridae, and Vespertilionidae. These species offer reliable viability for their acoustical identification (Barataud et al. 2013; this study). Even so, considering the high species richness for Brazil, for at least other 26 species of non-phyllotomid bats occurring in the country, there are neither published information on their echolocation calls nor sound files available to allow their identification. Indeed, some of these species are potentially very rare and difficult to capture or were recently described [e.g., *M. lavalii*, *M. izecksohni* (Moratelli et al. 2011)]. Obtaining acoustical data for those 26 species should be a priority for Brazil. The refinement of the information on their calls could also support the solution of taxonomic problems, joining more resolution

to molecular and/or morphological studies (e.g., Barratt et al. 1997; Thoisy et al. 2014).

Although the gaps in the acoustic knowledge of several species are a fact, here we showed that some other species are relatively easy to be identified acoustically. Due to species-specific calls, bioacoustics is widely used for several ecological and behavioral studies. This includes detailing species occurrence and distribution using acoustic monitoring schemes as a complement to mist-net sampling (e.g., Fenton et al. 1983; Ekman and de Jong 1996; Ahlén and Baag 1999). *Promops centralis* is one of those cases; due to its ecology and foraging behavior, mist-net records of this species are uncommon, however, this species has very distinctive calls allowing a fairly easy acoustic identification (Barataud et al. 2013; Jung et al. 2014). Accordingly to previous studies, in Brazil *P. centralis* was restricted to Amazonian states and to the state of Mato Grosso do Sul (Gregorin and Taddei 2000; Fischer et al. 2015). Using acoustic surveys in eight Brazilian states, it was possible to extend *P. centralis* distribution in more than 3,000,000 km<sup>2</sup> to the east (Hintze unpublished data), with less effort and more efficiently than using mist netting. This case is an important proof that when acoustic monitoring is effectively implemented, it will help to greatly improve our knowledge, filling the large gaps on the ecology, behavior, and distribution of poorly known Brazilian bat taxa.

Bioacoustics can be used to explore cryptic diversity in bats (Jones and Parisi 1993; Thoisy et al. 2014; Hintze et al. 2016c), and there is a great potential for this use in Brazil. A paradigmatic case in Europe was the discovery of two different sonotypes in what was thought to be colonies of *Pipistrellus pipistrellus* (45 and 55 kHz sonotypes) (Jones and Parisi 1993). This was the first clue to hypothesize the existence of two sympatric cryptic species (*P. pipistrellus* and *P. pygmaeus*) in the late 90s of the last century (Barratt et al. 1997; Jones and Barratt 1999). In the Neotropics, two similar cases are drawing attention to a new potential cryptic species complex. Thoisy et al. (2014) found *Pteronotus parnellii* individuals with different vocalizations living in sympatry (53 and 59 kHz sonotypes) both in French Guiana and northern Brazil, while Hintze et al. (2016c) hints for a new *Saccopteryx* species vocalizing with lower frequencies (39–42 kHz) than *S. bilineata* (45–48 kHz)—thus suggesting the existence of a larger species of the genus—the two potentially living in sympatry in the Atlantic Forest of northeastern Brazil. In the first case, morphological and molecular studies seem to support the presence of distinct species within the *Pteronotus parnellii* complex (Thoisy et al. 2014). In the latter study, despite the acoustic differences identified, captures will be necessary for the confirmation and morphological description of a new species (Hintze et al. 2016c).

Moreover, acoustic monitoring produces a huge amount of data, which results in a slow process of manual identification. But, while there has been some improvement in automated

**Table 6** Summary of echolocation call parameters as retrieved from the literature and our own data for species of the Vespertilionidae, with information on region of recording and IUCN status of each species

Species	IUCN	Region	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	SI
<i>Eptesila</i>	LC	NA-Tr-Ar-WT		55.83 ± 11.48 (20.56)	33.30 ± 3.46 (10.40)	37.12 ± 6.07 (16.35)	32.93 ± 3.46 (10.51)	55.83 ± 11.48 (20.56)	22.89 ± 8.93 (39.01)	7.80 ± 3.77 (48.33)		47
<i>Eptesila</i>	LC	SA-Tr		70.43 (63.26–75.21)	34.34 (32.24–36.72)	44.61 (40.24–49.60)	34.33 (32.24–36.63)	70.48 (63.38–75.21)	36.15 (29.0–40.66)	3.5 (2.70–4.18)	100.1 ± 26.4	38
						43.6 ± 2.7	40.0 ± 0.6	58.0 ± 8.5	17.9 ± 8.7	3.1 ± 0.4		35
<i>Eptesila</i>		CI-Tr	Fm with qcf tail		25–39	41.1 ± 1.3	30.5 ± 6.4	71.5 ± 14.8		3.0 ± 1.6	74.7 ± 23.3	25
<i>Eptesila</i>	LC	SA-Tr	Fm flat			32 ± 2.6		30 ± 11.3		7.6 ± 1.6		3
<i>Eptesila</i>	DD	SA-WT				66.37 ± 3.36	40.45 ± 1.59	82.89 ± 6.41	42.43 ± 6.45	1.8 ± 0.37	50.78 ± 25.42	41
<i>Eptesila</i>	LC	NA-Tr				37.6 ± 1.3	36.4 ± 1.4	40.4 ± 2.1		7.1 ± 1.9	175.8 ± 78.3	28
							32.78	64.02				23
							33.1 ± 0.5			9.4 ± 0.5		40
			Fm down. Ends with narrow-band "tail"									
<i>Eptesila</i>	NA	NA-Tr-Ar-WT		56.34 ± 8.69 (15.42)	37.40 ± 1.45 (3.88)	39.77 ± 3.55 (8.93)	37.05 ± 1.23 (3.32)	56.34 ± 8.69 (15.42)	19.29 ± 8.74 (45.31)	6.91 ± 1.72 (24.89)		47
<i>Laslo</i>	LC	CA-Tr					37.5 ± 1.13	52.6 ± 8.61		5.5 ± 1.58		30
		SA-Tr	Fm flat		35–45	41.6 ± 2			36.1 ± 9.8	6 ± 1.3		3
			Fm with qcf tail								139.2 ± 79.8	25
			Fm qcf			38.7 ± 1.5	36.2 ± 0.6	63.0 ± 9.1	26.9 ± 8.9	6.1 ± 0.5		34
										>8		18
		NA-Ar-WT	Low slope			41.6 (37–61)	38.8 (36–52)	54.6 (44–102)		10.7 (2.9–14)		23
		NA-WT-Sn	U-shaped				46.84	62.67				8
		NA-Tr					43.58 ± 1.36	62.89 ± 1.14		6.11 ± 1.67		47
		NA-Tr-Ar-WT	Fm down qcf	89.58 ± 10.56 (11.79)	39.49 ± 5.93 (15.02)	53.75 ± 10.72 (19.94)	39.49 ± 5.93 (15.02)	90.03 ± 10.66 (11.84)	50.54 ± 9.18 (18.16)	3.29 ± 1.28 (38.91)		20
		CA-Tr	Fm			46						3
		SA-Tr		70.92 (66.06–74.41)	35.96 (34.54–37.16)	45.5 ± 5.3			14.3 ± 7	12.3 ± 2.5		38
			Fm down. Irregular and alternating sequences	40–45	38.77 (37.27–41.13)		35.85 (34.54–36.97)	70.92 (66.06–74.41)	35.07 (30.57–38.20)	6.17 (5.38–7.22)		25
<i>Laslo</i>	DD	SA-Tr	Fm down. Irregular and alternating sequences	25–35								25
<i>Laslo</i>	LC	NA-WT-Sn	Pronounced or subtle U-shape									6
		NA-Ar				27.43 ± 2.24	24.72 ± 1.79	39.61 ± 5.08		8.92 ± 1.45		30
						29.24 ± 2.80	25.90 ± 3.05	42.36 ± 6.31		5.46 ± 2.31		18
							21.9 ± 2.36	30.8 ± 7.18		8.2 ± 2.82		30
							22.0 ± 1.89	40.8 ± 7.03		6.2 ± 3.11		18
						20.8	19.7	26		11		47
<i>Laslo</i>	DD	NA-Tr-Ar-WT		57.23 ± 7.92 (13.84)	26.81 ± 4.39 (16.37)	35.47 ± 7.11 (20.05)	26.79 ± 4.39 (16.39)	57.24 ± 7.92 (13.84)	30.45 ± 5.12 (16.81)	4.25 ± 1.39 (32.71)		40
<i>Laslo</i>	LC	NA-Tr-Ar	Long down-sweeps. Ends with short narrow-band "tail"			31.3 ± 1.3	27.3 ± 2.5			9.4 ± 1.2		28
											149.4 ± 64.7	23
						32.2 ± 1.2	31.1 ± 1.4	34.9 ± 1.6		8.7 ± 2.5		47
							35.49	43.97				30
							37.45 ± 0.98 (2.62)	61.13 ± 4.50 (7.36)	23.68 ± 4.89 (20.65)	2.93 ± 0.51 (17.41)		44
							32.0 ± 2.45	43.0 ± 8.64		6.6 ± 2.73		20
						32						25
						32						25
			Fm down qcf									
			Fm down. Irregular and alternating sequences	25–35								

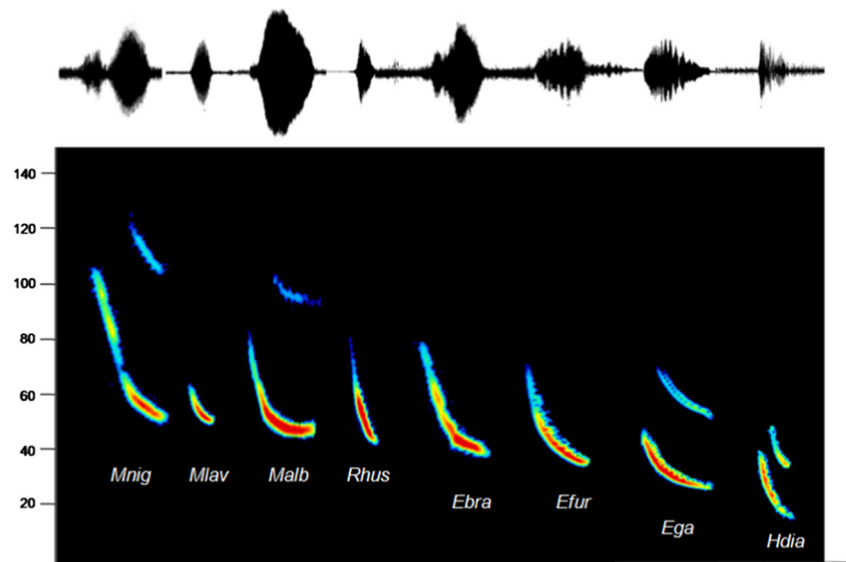


**Table 6** (continued)

Species	IUCN	Region	Structure	SF (kHz)	EF (kHz)	FME (kHz)	LF (kHz)	HF (kHz)	BW (kHz)	CD (ms)	PI (ms)	SI
<i>Lasegr</i>	DD	SA-Tr	Fm down. Irregular and alternating sequences	45.4 ± 7.1	27.3 ± 1.9 25–35	30.2 ± 3.5				4.8 ± 1.3		24 25
<i>Laasal</i>	NA											
<i>Htsali</i>	DD											
<i>Htsdia</i>	NA	SA-Tr	Fm	37.3 ± 2.6	15.3 ± 0.6	28.3 ± 4.0	15.3 ± 0.6	37.3 ± 2.6	22.0 ± 2.6	2.8 ± 1.2	113.7 ± 81.1	5
<i>Htslae</i>	NT	SA-Ar	Fm	38.1 ± 2.6	26.3 ± 1.8	30.3 ± 3.6				1.3 ± 0.3	89.6 ± 55.7	33
<i>Htsmon</i>	LC	SA-Ar	Fm	46.3 ± 4.5	25.4 ± 2.1	32.0 ± 2.1				3.6 ± 2.6	147.1 ± 75.3	33
				53.77 ± 0.97	29.62 ± 0.25	35.36 ± 0.41	31.28 ± 0.31	44.62 ± 0.91		3.34 ± 0.08	136.12 ± 8.03	39
<i>Htsvel</i>	DD	SA-WT				42	15	25		5–8		12
<i>Myoalb</i>	LC	CA-Tr	Fm-down qcf Downward steep FM-shallow		43–46	52						44
			modulated									20
<i>Myodin</i>	LC	SA-Tr	Fm-qcf down	92.69 (84.78–100.82)	51.4 (47.44–56.48)	64.00 (57.28–72.61)	51.38 (47.44–56.45)	92.71 (84.83–100.82)	41.33 (34.07–47.99)	2.45 (1.86–3.03)	62.8 ± 17.2	38
<i>Myoize</i>	NA					80.5 ± 9.6	51.4 ± 2.4	125.9 ± 7.0	74.5 ± 7.6	2.5 ± 0.4		o
<i>Myolav</i>	NA											
<i>Myolev</i>	LC	SA-WT				65.65 ± 3.64	46.00 ± 1.35	80.84 ± 3.28	34.84 ± 3.54	1.5 ± 0.28	77.2 ± 28.48	41
<i>Myonig</i>	LC	CA-Tr	Fm-down qcf Downward steep FM-shallow		48–55	55				7.2 ± 0.3	106.2 ± 11.2	42
			modulated			54.2 ± 0.04				4.3 ± 0.5	67.6 ± 13.1	44
						55.00						20
						55						10
<i>Myorip</i>	LC	CI-Tr	Fm-down qcf Downward steep FM-shallow		48–55							
			modulated									
			Fm flat			53.7 ± 4			28.5 ± 11.7	4.3 ± 1.2		3
		SA-Tr	Structure	76.86 (69.10–84.63)	38.56 (36.05–43.94)	48.25 (42.67–55.79)	38.53 (36.05–43.94)	76.9 (69.18–84.63)	38.37 (30.47–43.93)	3.41 (2.54–4.11)		38
			Fm with qcf tail		45–50							25
			Fm-qcf down			55.0 ± 1.4	52.9 ± 1.1	67.1 ± 3.8	14.2 ± 4.1	3.8 ± 0.7	63.8 ± 18.4	o
		CI-Tr				66.2 ± 7.9	51.3 ± 1.3	125.0 ± 7.5		2.2 ± 0.1	24.0 ± 6.2	35
		CA-Tr	Downward steep FM-shallow		58–60							10
			modulated									
			Fm/qcf			> 56						2
		SA-Tr	Fm/qcf			58.1 ± 2.5			40.7 ± 11.8	5 ± 1.3		3
						55 ± 1.8			37.4 ± 9.5	5.2 ± 1.1		3
						66.56 (64.36–70.21)	61.57 (60.48–62.74)	102.8 (99.04–106.43)	41.16 (36.90–44.74)	4.38 (3.77–5.36)		38
			Fm with qcf tail	102.71 (98.60–106.43)	61.6 (60.48–63.12)							25
				> 55								12
<i>Myorub</i>	NT	SA-WT					50	58		4–5		12
<i>Myosin</i>	DD	SA-WT					58	65		5		12
<i>Rholus</i>	DD											
<i>Rhoio</i>	LC	SA-Tr	Steep fm			48.2 ± 4.7	41.5 ± 0.8	59.8 ± 2.5	18.3 ± 2.5	3.6 ± 0.2	89.3 ± 7.3	o
		SA-Tr	Fm down. Irregular and alternating sequences		40–45							25
		CI-Tr				52.4 ± 3.7	39.6 ± 3.9	99.6 ± 6.5		2.8 ± 0.6	38.4 ± 28.6	35

SF start frequency, EF end frequency, FME frequency of maximum energy, LF lowest frequency, HF highest frequency, BW bandwidth, CD call duration, PI pulse interval, SI reference number and species name abbreviations in Appendix 1

**Fig. 6** Echolocation calls for species of Vespertilionidae known to occur, or potentially occurring, in Brazil. Call duration and pulse intervals are not scaled. Mnig *Myotis nigricans*, Mlav *Myotis lavalii*, Malb *Myotis albescens*, Rhus *Rhogeessa hussoni*, Ebra *Eptesicus brasiliensis*, Efur *Eptesicus furinalis*, Lega *Lasiurus ega*, Hdia *Histiotus diaphanopterus*



identification tools these programs support, their identifications are usually based on limited libraries of calls and much too often in calls collected in a few restricted regions (Russo and Voigt 2016). Biologists working with bat echolocation identification should still resist the temptation of solely using automatic classifiers (Russo and Voigt 2016). Neglecting the possibility of regional variation in the echolocation calls of the species and the potential for cryptic Neotropical bat diversity (Thoisy et al. 2014; Hintze et al. 2016c), the passive acceptance of potentially inaccurate and incorrect automated identifications (Hintze et al. 2016a) may lead to deficient species data records and consequently to serious problems in bat conservation (Russo and Voigt 2016). This does not mean that we should be discouraged to develop better-automated identification tools, based on comprehensive sound databases and powerful algorithms. Nonetheless, we must accept that perhaps some species may never be distinguished because they overlap too much in call parameters; indeed, after decades of studies, recordings and analyses, the acoustic discrimination of several species of European *Myotis* remains a huge challenge for bat researchers (e.g., Barataud 2015).

Also, comparison among studies to detect geographical variation, the actual magnitude of such variation, and potential cryptic complexes of species suggested by significant acoustic variation will only be possible if recording and analytical procedures are detailed in the published information.

The construction of bat sound libraries, as Xeno-Canto for birds, is highly desirable to progress in bioacoustics. For this, it seems very important that every expert adopt a similar recording protocol. Indeed, high-flying bats (in particular molossid and some vespertilionids like *Lasiurus*) turn out recognizable during cruising or hunting flight at high altitude. In vegetation edges, or near the ground, they produce very

similar sounds, which are thus difficult to identify. Consequently, the production of reference sounds for high-flying bats should respect some criteria: a rather long acoustic sequence which includes take-off, ascent towards the sky (and thus generally a swirling flight near edges) and a high cruise flight in open environment. This type of recording supplies all fundamental acoustic features of those species.

Consequences of these gaps in knowledge are straightforward. First, we will have a lot to learn and update on bat species diversity, occurrence, distribution and conservation status in the Neotropics as already exemplified by the *P. centralis* and *P. cf. parnellii* cases mentioned above. Second, we will not be able to use automated acoustic identification programs until comprehensive databases of Neotropical bat calls are available. Indeed, Hintze et al. (2016a) found that the accuracy level (percentage of correct identifications) of two widespread automated acoustic identification programs is quite low (below 12%) for Brazilian bats easily manually identified by bat acoustic experts. They also point out the need for those software and their classifiers to undergo much improvement and validation tests before being publicized in the market for wide use in acoustic identification of bats in Brazil. And third, as climate influences some aspects of the ecology and behavior of the species including foraging behavior and biogeography, the actual rate of climate change represents a serious and increasing threat to biodiversity (Sherwin et al. 2013), with unknown effects on the actual species distribution as well on the acoustics profiles of Brazilian bats.

We need to accept this as a great challenge for the next few years: the need to collect good acoustic data for all species and especially for those for which we have no information. This will improve our identifications and contribute to the construction of more comprehensive sound libraries for manual and automated identification, and to better understand the patterns of bat

diversity in Brazil and the Neotropical region as a whole. So, in conclusion, the use of bioacoustics can be a fundamental tool to expand the knowledge on Brazilian bats and improve their conservation. We hope that this will be the initiating spark for the sustained growth of the bat bioacoustics in Brazil.

**Acknowledgments** The authors thank Eder Barbier who kindly sent personal recordings and information of *H. diaphanopterus* and Ítalo K. Rakowski who helped with the digitalization of data. A. Arias-Aguilar and F. Hintze were supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) with MS and Ph.D. grants, respectively. E. Bernard was supported with a National Counsel of Technological and Scientific Development (CNPq) productivity grant.

## References

- Ahlén I, Baag HJ (1999) Use of ultrasound detectors for bat studies in Europe: experiences from field identification, surveys, and monitoring. *Acta Chiropterol* 1:137–150
- Alho C, Fischer E, Oliveira-Pissini L, Santos C (2011) Bat-species richness in the Pantanal floodplain and its surrounding uplands. *Braz J Biol* 71:311–320
- Appleton BR, McKenzie JA, Christidis L (2004) Molecular systematics and biogeography of the bent-wing bat complex *Miniopterus schreibersii* (Kuhl, 1817) (Chiroptera: Vespertilionidae). *Mol Phylogenet Evol* 31:431–439
- Arias-Aguilar A, Chacón-Madrigal E, Rodríguez-Herrera B (2015) El uso de los parques urbanos con vegetación por murciélagos insectívoros en San José, Costa Rica. *Mastozool Neotrop* 22:229–237
- Arlettaz R, Jones G, Racey PA (2001) Effect of acoustic clutter on prey detection by bats. *Nature* 414:742–745
- Bader E, Jung K, Kalko EKV, Page RA, Rodriguez R, Sattler T (2015) Mobility explains the response of aerial insectivorous bats to anthropogenic habitat change in the Neotropics. *Biol Conserv* 186:97–106
- Barataud, M. 2015. Acoustic ecology of European bats. *Species Identification and Studies of Their Habitats and Foraging Behaviour*. Biotope Editions, Mèze; National Museum of Natural History, Paris (collection Inventaires et biodiversité), 340 p
- Barataud M, Giosa S, Leblanc F, Rufroy V, Disca T, Tillon L, Delaval M, Haquart A, Dewynter M (2013) Identification et écologie acoustique des chiroptères de Guyane Française. *Le Rhinolophe* 19:103–145
- Barquez R, Perez S, Miller B, Diaz M (2015a) *Noctilio albiventris*. In: The IUCN Red List of Threatened Species 2015: e.T14829A22019978 [Internet]. Available from: <https://doi.org/10.2305/IUCN.UK.2015-4.RLTS.T14829A22019978.en>. Accessed 8 December 2016
- Barquez R, Perez S, Miller B, Diaz M (2015b) *Noctilio leporinus*. In: The IUCN Red List of Threatened Species 2015: e.T14830A22019554 [Internet]. Available from: <https://doi.org/10.2305/IUCN.UK.2015-4.RLTS.T14830A22019554.en>. Accessed 8 December 2016
- Barratt E, Deaville R, Burland T, Bruford MW (1997) DNA answers the call of pipistrelle bat species. *Nature* 387:138–139
- Bartlett SN, McDonough MM, Ammerman LK (2013) Molecular systematics of bonneted bats (Molossidae: Eumops) based on mitochondrial and nuclear DNA sequences. *J Mammal* 94:867–880
- Bernard E, Aguiar LMS, Machado RB (2011) Discovering the Brazilian bat fauna: a task for two centuries? *Mamm Rev* 41:23–39
- Bernardi IP, Miranda JMD, Passos FC (2009) Status taxonômico e distribucional do complexo *Eumops bonariensis* (Chiroptera: Molossidae) no sul do Brasil. *Zoologia (Curitiba)* 26:183–190
- Borloti I, Almeida M, Mischiatti F, Tokumaru R, Ditchfield A (2014) Repertório sonoro de ecolocalização de *Molossus molossus* (Chiroptera, Molossidae). III Simpósio Sobre A Biodiversidade Da Mata Atlântica. <http://www.boletimmbml.net/simbioma/simbioma%20iii/45.pdf>. Accessed 30 november 2016
- Briones-Salas M, Peralta-Pérez M, García-Luis M (2013) Acoustic characterization of new species of bats for the state of Oaxaca, Mexico. *Therya* 4:15–32
- Catzefflis F, Gager Y, Ruedi M, de Thoisy B (2016) The French Guianan endemic *Molossus barnesi* (Chiroptera: Molossidae) is a junior synonym for *M. coibensis*. *Mamm Biol* 81:431–438
- Christidis L, Goodman SM, Naughton K, Appleton B (2014) Insights into the evolution of a cryptic radiation of bats: dispersal and ecological radiation of Malagasy *Miniopterus* (Chiroptera: Miniopteridae). *PLoS One* 9:e92440
- Clare EL, Lim BK, Engstrom MD, Eger JL, Hebert PDN (2007) DNA barcoding of Neotropical bats: species identification and discovery within Guyana. *Mol Ecol Notes* 7:184–190
- Clare EL, Adams AM, Maya-Simões AZ, Eger JL, Hebert PD, Fenton MB (2013) Diversification and reproductive isolation: cryptic species in the only New World high-duty cycle bat, *Pteronotus parnellii*. *BMC Evol Biol* 13:26
- Cunto GC, Bernard E (2012) Neotropical bats as indicators of environmental disturbance: what is the emerging message? *Acta Chiropterol* 14:143–151
- Delgado-Jaramillo M, Barbier E, Bernard E (2017) New records, potential distribution, and conservation of the near threatened cave bat *Natalus macrourus* in Brazil. *Oryx*:1–8. <https://doi.org/10.1017/S0030605316001186>
- Denzinger A, Schnitzler HU (2013) Bat guilds, a concept to classify the highly diverse foraging and echolocation behaviors of microchiropteran bats. *Front Physiol* 4:164. <https://doi.org/10.3389/fphys.2013.00164>
- Ekman M, de Jong J (1996) Local patterns of distribution and resource utilization of four bat species (*Myotis brandti*, *Eptesicus nilsoni*, *Plecotus auritus* and *Pipistrellus pipistrellus*) in patchy and continuous environments. *J Zool* 238:571–580
- Espinal M, Mora JM (2015) Ampliación en la distribución de cinco especies de murciélagos en Honduras basada en detección por medios acústicos. *Ceiba* 53:30–37
- Estrada-Villegas S, McGill BJ, Kalko EKV (2012) Climate, habitat, and species interactions at different scales determine the structure of a Neotropical bat community. *Ecology* 93:1183–1193
- Falcão F, Ugarte-Núñez JA, Faria D, Caselli CB (2015) Unravelling the calls of discrete hunters: acoustic structure of echolocation calls of furipterid bats (Chiroptera, Furipteridae). *Bioacoustics* 24:175–183
- Feijó A, Rocha PAD, Althoff SL (2015) New species of *Histiotus* (Chiroptera: Vespertilionidae) from northeastern Brazil. *Zootaxa* 4048:412–427
- Fenton MB, Merriam HG, Holroyd GL (1983) Bats of Kootenay, glacier, and Mount Revelstoke national parks in Canada: identification by echolocation calls, distribution, and biology. *Can J Zool* 61:2503–2508
- Fenton MB, Rydell J, Vohof MJ, Eklöf J, Lancaster WC (1999) Constant-frequency and frequency-modulated components in the echolocation calls of three species of small bats (Emballonuridae, Thyropteridae, and Vespertilionidae). *Can J Zool* 77:1891–1900
- Fenton MB, Bouchard S, Vohof MJ, Zigouris J (2001) Time-expansion and zero-crossing period meter systems present significantly different views of echolocation calls of bats. *J Mammal* 82:721–727
- Fischer E, Santos CF, Carvalho LFA, Camargo G, Cunha NL, Silveira M, Bordignon MO, Silva CL (2015) Bat fauna of Mato Grosso do Sul, southwestern Brazil. *Biota Neotrop* 15. [doi.org/10.1590/1676-06032015006614](https://doi.org/10.1590/1676-06032015006614)
- Furman A, Öztunç T, Çoraman E (2010a) On the phylogeny of *Miniopterus schreibersii schreibersii* and *Miniopterus schreibersii*

- pallidus* from Asia Minor in reference to other *Miniopterus* taxa (Chiroptera: Vespertilionidae). *Acta Chiropterol* 12:61–72
- Furman A, Öztunç T, Postawa T, Çoraman E (2010b) Shallow genetic differentiation in *Miniopterus schreibersii* (Chiroptera: Vespertilionidae) indicates a relatively recent re-colonization of Europe from a single glacial refugium. *Acta Chiropterol* 12:51–59
- Gager Y, Tarland E, Lieckfeldt D, Ménage M, Botero-Castro F, Rossiter SJ, Kraus RHS, Ludwig A, Dechmann DKN (2016) The value of molecular vs. morphometric and acoustic information for species identification using sympatric molossid bats. *PLoS One* 11: e0150780
- Garbino GS, Tejedor A (2013) *Natalus macrourus* (Gervais, 1856) (Chiroptera: Natalidae) is a senior synonym of *Natalus espiritosantensis* (Ruschi, 1951). *Mammalia* 77:237–240
- Government of Alberta Fish and Wildlife Division (2006) Wildlife guidelines for Alberta wind energy projects. Alberta Sustain Resour Dev, Alberta, p 11
- Gregorin R, Taddei V (2000) New records of *Molossus* and *Promops* from Brazil (Chiroptera: Molossidae). *Mammalia* 64:471–476
- Gregorin R, Moras LM, Acosta LH, Vasconcellos KL, Poma JL, dos Santos FR, Paca RC (2016) A new species of *Eumops* (Chiroptera: Molossidae) from southeastern Brazil and Bolivia. *Mamm Biol* 81:235–246
- Greif S, Siemers BM (2010) Innate recognition of water bodies in echolocating bats. *Nat Commun* 1:107
- Grinnell AD, Gould E, Fenton MB (2016) A history of the study of echolocation. In: Fenton MB, Grinnell AD, Popper AN, Fay RR (eds) *Bat Bioacoustics*. Springer New York, New York pp. 1–24
- Heer K, Helbig-Bonitz M, Fernandes RG, Mello MAR, Kalko EKV (2015) Effects of land use on bat diversity in a complex plantation—forest landscape in northeastern Brazil. *J Mammal* 96:720–731
- Hintze F, Arias-Aguilar A, Aguiar LMS, Ramos Pereira MJ, Bernard E (2016a) Uma nota de precaução sobre a identificação automática de chamados de ecolocalização de morcegos no Brasil. *Boletim da Sociedade Brasileira de Mastozoologia* 77:163–171
- Hintze F, Duro V, Carvalho JC, Eira C, Rodrigues PC, Vingada J (2016b) Influence of reservoirs created by small dams on the activity of bats. *Acta Chiropterol* 18:395–408
- Hintze F, Barbier E, Bernard E (2016c) Emballonuridae Gervais, 1855 (Chiroptera) of Reserva Biológica de Salinho (Atlantic Forest), in Brazil, revealed by echolocation. *Check List* 12:1–9
- IUCN. 2016. The IUCN red list of threatened species. Version 2016-3. Available from: <http://www.iucnredlist.org/>. Accessed 20 February 2016
- Jiang T, Wu H, Feng J (2015) Patterns and causes of geographic variation in bat echolocation pulses. *Integr Zool* 10:241–256
- Jones G, Barratt E (1999) *Vespertilio pipistrellus* Schreber, 1774 and *V. pygmaeus* Leach, 1825 (currently *Pipistrellus pipistrellus* and *P. pygmaeus*; Mammalia, Chiroptera): proposed designation of neotypes. *Bull Zool Nomencl* 56:182–186
- Jones G, Parijs SMV (1993) Bimodal echolocation in pipistrelle bats: are cryptic species present? *Proc R Soc Lond B Biol Sci* 251:119–125
- Jung K, Kalko EKV (2011) Adaptability and vulnerability of high flying Neotropical aerial insectivorous bats to urbanization. *Divers Distrib* 17:262–274
- Jung K, Kalko EKV, Von Helversen O (2007) Echolocation calls in central American emballonurid bats: signal design and call frequency alternation. *J Zool* 272:125–137
- Jung K, Molinari J, Kalko EKV (2014) Driving factors for the evolution of species-specific echolocation call design in new world free-tailed bats (Molossidae). *PLoS One* 9:e85279
- Kalko EKV, Handley CO (2001) Neotropical bats in the canopy: diversity, community structure, and implications for conservation. *Plant Ecol* 153:319–333
- Kalko EKV, Schnitzler H (1998) How echolocating bats approach and acquire food. In: Kunz TH, Racey PA (eds) *Bat biology and conservation*. Smithsonian Institution Press, Washington, DC, pp 197–204
- Kalko EKV, Estrada Villegas S, Schmidt M, Wegmann M, Meyer CFJ (2008) Flying high—assessing the use of the aerosphere by bats. *Integr Comp Biol* 48:60–73
- Kraker-Castañeda C, Santos-Moreno A, García-García JL (2013) Riqueza de especies y actividad relativa de murciélagos insectívoros aéreos en una selva tropical y pastizales en Oaxaca, México. *Mastozool Neotrop* 20:255–267
- Kunz TH, Parsons S (2009) *Ecological and behavioral methods for the study of bats*. Johns Hopkins University Press, Baltimore
- Lewinsohn TM, Prado PI (2005) How many species are there in Brazil? *Conserv Biol* 19:619–624
- López-Baucells A, Rocha R, Bobrowiec P, Bernard E, Palmeirim J, Meyer C (2016) Field guide to amazonian bats. Editora INPA, Manaus
- López-Wilchis R, Flores-Romero M, Guevara-Chumacero LM, Serrato-Díaz A, Díaz-Larrea J, Salgado-Mejía F, Ibañez C, Salles LO, Juste J (2016) Evolutionary scenarios associated with the *Pteronotus parnellii* cryptic species-complex (Chiroptera: Mormoopidae). *Acta Chiropterol* 18:91–116
- Marques JT, Ramos Pereira M, Palmeirim J (2015) Patterns in the use of rainforest vertical space by Neotropical aerial insectivorous bats: all the action is up in the canopy. *Ecography* 38:001–011. <https://doi.org/10.1111/ecog.01453>
- Miller-Butterworth CM, Eick G, Jacobs DS, Schoeman MC, Harley EH (2005) Genetic and phenotypic differences between south African long-fingered bats, with a global miniopterine phylogeny. *J Mammal* 86:1121–1135
- Mittermeier RA, Myers N, Thomsen JB, Da Fonseca GAB, Olivieri S (1998) Biodiversity hotspots and major tropical wilderness areas: approaches to setting conservation priorities. *Conserv Biol* 12: 516–520
- Moras LM, Tavares V, Pepato AR, Santos FR, Gregorin R (2016) Reassessment of the evolutionary relationships within the dog-faced bats, genus *Cynomops* (Chiroptera: Molossidae). *Zool Scr* 45:465–480
- Moratelli R, Peracchi AL, Dias D, de Oliveira JA (2011) Geographic variation in south American populations of *Myotis nigricans* (Schinz, 1821) (Chiroptera, Vespertilionidae), with the description of two new species. *Mamm Biol* 76:592–607
- Nogueira MR, de Lima IP, Moratelli R, da Cunha Tavares V, Gregorin R, Peracchi AL (2014) Checklist of Brazilian bats, with comments on original records. *Check List* 10:808–821
- Novaes RLM, Souza R, Felix S, Sauwen C, Jacob G, Avilla LS (2012) New record of *Furipterus horrens* (Cuvier, 1828) (Mammalia, Chiroptera) from the Cerrado of Tocantins state with a compilation of the known distribution within Brazil. *Check List* 8:1359–1361
- Nowak RM (1994) *Walker's bats of the world*. Johns Hopkins University Press, Baltimore
- Ochoa J, O'Farrell MJ, Miller BW (2000) Contribution of acoustic methods to the study of insectivorous bat diversity in protected areas from northern Venezuela. *Acta Chiropterol* 2:171–183
- O'Farrell MJ, Miller BW (1997) A new examination of echolocation calls of some neotropical bats (Emballonuridae and Mormoopidae). *J Mammal* 78:954–963
- O'Farrell MJ, Miller BW (1999) Use of vocal signatures for the inventory of free-flying neotropical bats. *Biotropica* 31:507–516
- O'Farrell MJ, Miller BW, Gannon WL (1999) Qualitative identification of free-flying bats using the anabat detector. *J Mammal* 80:11–23
- Ontario Ministry of Natural Resources (2011) *Bat and bat habitats: guidelines for wind power projects*. Ontario Ministry of Natural Resources, Ontario, p 24
- Orozco-Lugo L, Guillén-Servent A, Valenzuela-Galván D, Arita HT (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
- Ossa G, Forero L, Novoa F, Bonacic C (2015) Caracterización morfológica y bioacústica de los murciélagos (Chiroptera) de la Reserva Nacional Pampa de Tamarugal. *Conservación, gestión y manejo de áreas silvestres protegidas. Biodiversidata* 3:21–29
- Paglia AP, da Fonseca GA, Rylands AB, Herrmann G, Aguiar LM, Chiarello AG, Leite YL, Costa LP, Siciliano S, Kierulff MCM (2012) Lista anotada dos mamíferos do Brasil 2ª Edição. *Occasional Papers Conservation Biology* 6:76
- Passos FC, Miranda JM, Bernardi IP, Kaku-Oliveira NY, Munster LC (2010) Morcegos da Região Sul do Brasil: análise comparativa da riqueza de espécies, novos registros e atualizações nomenclaturais (Mammalia, Chiroptera). *Iheringia, Série Zoologia* 100:25–34
- Peel MC, Finlayson BL, McMahon TA (2007) Updated world map of the Köppen-Geiger climate classification. *Hydrol Earth Syst Sci Discuss* 4:439–473
- Ramos Pereira MJ, Barros M, Chaves TS, Rui AM, Dotto JC, Braun A, Barbosa J, Bernard E, Aguiar LMS, Kindel A, Sana DA (2017) Guidelines for consideration of bats in environmental impact assessment of wind farms in Brazil: a collaborative governance experience from Rio Grande do Sul. *Oecologia Australis* 21:232–255. <https://doi.org/10.4257/oeco.2017.2103.02>
- Rivera-Parra P, Burneo SF (2013) Primera biblioteca de llamadas de ecolocalización de murciélagos del Ecuador. *Therya* 4:79–88
- Rocha PA, Mikaluskas JS, Bocchiglieri A, Feijó JA, Ferrari SF (2013) An update on the distribution of the Brazilian funnel-eared bat, *Natalus macrourus* (Gervais, 1856) (Mammalia, Chiroptera), with new records from the Brazilian Northeastern. *Check List* 9:675–679
- Rodrigues L, Bach L, Dubourg-Savage B, Karapandža D, Kovac T, Kervyn J, Dekker A, Kepel P, Bach J, Collins C (2015) Guidelines for consideration of bats in wind farm projects—revision 2014. EUROBATS Publication, UNEP/EUROBATS Secretariat, Bonn
- Rodríguez-San Pedro A, Simonetti JA (2013) Acoustic identification of four species of bats (order Chiroptera) in Central Chile. *Bioacoustics* 22:165–172
- Russo D, Voigt CC (2016) The use of automated identification of bat echolocation calls in acoustic monitoring: a cautionary note for a sound analysis. *Ecol Indic* 66:598–602
- Russo D, Cistrone L, Jones G (2012) Sensory ecology of water detection by bats: a field experiment. *PLoS One* 7:e48144
- Rydell J, Arita H, Santos M, Granados J (2002) Acoustic identification of insectivorous bats (order Chiroptera) of Yucatan, Mexico. *J Zool* 257:27–36
- Sampaio EM, Kalko EKV, Bernard E, Rodríguez-Herrera B, Handley CO (2003) A biodiversity assessment of bats (Chiroptera) in a tropical lowland rainforest of Central Amazonia, including methodological and conservation considerations. *Stud Neotrop Fauna Environ* 38:17–31
- Schnitzler HU, Moss CF, Denzinger A (2003) From spatial orientation to food acquisition in echolocating bats. *Trends Ecol Evol* 18:386–394
- Sherwin HA, Montgomery WI, Lundy MG (2013) The impact and implications of climate change for bats. *Mammal Review* 43:171–182
- Simmons NB, Wilson D, Reeder D (2005) Order chiroptera. In: Wilson DE, Reeder DM (eds) *Mammal species of the world: a taxonomic and geographic reference*. Johns Hopkins University Press, Baltimore, pp 312–529
- Skowronski MD, Fenton MB (2008) Model-based detection of synthetic bat echolocation calls using an energy threshold detector for initialization. *J Acoust Soc Am* 123(5):2643–2650
- Tejedor A, Davalos LM (2016) *Natalus espirosantensis*. In: The IUCN Red List of Threatened Species: e.T136448A21983924 [Internet]. Available from: <https://doi.org/10.2305/IUCN.UK.2016-2.RLTS.T136448A21983924.en>. Accessed 8 December 2016
- Thoisy BD, Pavan AC, Delaval M, Lavergne A, Luglia T, Pineau K, Ruedi M, Rufay V, Catzeflis F (2014) Cryptic diversity in common mustached bats *Pteronotus cf. parnellii* (Mormoopidae) in French Guiana and Brazilian Amapa. *Acta Chiropterol* 16:1–13
- Valença RB, Bernard E (2015) Another blown in the wind: bats and the licensing of wind farms in Brazil. *Nat Conserv* 13:117–122
- Vaughan N, Jones G, Harris S (1997) Habitat use by bats (chiroptera) assessed by means of a broad-band acoustic method. *J Appl Ecol* 34:716–730
- Velazco PM (2005) Morphological phylogeny of the bat genus *Platyrrhinus Saussure*, 1860 (Chiroptera: Phyllostomidae) with the description of four new species. *Fieldiana Zool* 105:1–53
- Velazco PM, Patterson BD (2013) Diversification of the yellow-shouldered bats, genus *Sturnira* (Chiroptera, Phyllostomidae), in the New World tropics. *Mol Phyl Evol* 68:683–698
- Velazco PM, Gregorin R, Voss RS, Simmons NB (2014) Extraordinary local diversity of disk-winged bats (Thyropteridae: Thyroptera) in northeastern Peru, with the description of a new species and comments on roosting behavior. *Am Mus Novit* 3795:1–28
- Willig MR (1985) Reproductive patterns of bats from Caatingas and Cerrado biomes in Northeast Brazil. *J Mammal* 66:668–681
- Zamora-Gutierrez V, Lopez-Gonzalez C, MacSwiney MC, Fenton B, Jones G, Kalko EKV, Puechmaille SJ, Stathopoulos V, Jones KE (2016) Acoustic identification of Mexican bats based on taxonomic and ecological constraints on call design. *Methods Ecol Evol* 7:1082–1091