Echolocation Call Characteristics of Eastern US Bats

	species	f_c	hi f	lo f	f_{maxE}	dur	uppr slp	lwr slp	slp @Fc	total slp	special characteristics
50 to 40 Myotis	***Myotis grisescens*** **gray bat**	***45.7*** ***47*** ***44*** 41-51	***79.5*** ***91*** ***68*** 53-107	***41.8*** ***44*** ***40*** 37-46	***48.2*** ***52*** ***44*** 41-85	***7.2*** ***8.5*** ***5.8*** 2.4-10	***11.5*** ***15*** ***8.3*** 3.6-29	***2.0*** ***3.1*** ***0.9*** 0.5-12	***2.4*** ***4.2*** ***0.5*** 0.0-13	***4.8*** ***7.6*** ***2.0*** 1.3-20	Longer calls (>5ms) typically display a **strong inflection point at the knee, pronounced downward tail ending call**, and an **extended call body with broad amplituded distribution**. Shorter calls (3-5 ms) are typically at a higher frequency than other geographically overlapping Myotis.
	Myotis leibii **eastern small–footed myotis**	***44.3*** ***46*** ***42*** *38-48*	***95.1*** ***104*** ***86*** *55-115*	***40.6*** ***42*** ***39*** *31-44*	***49.1*** ***52*** ***46*** *40-71*	***3.2*** ***3.9*** ***2.5*** *1.7-5.3*	***33.5*** ***40*** ***27*** *6.9-48*	***9.6*** ***12*** ***7.0*** *2.5-22*	***8.9*** ***12*** ***5.5*** *0.0-28*	***16.9*** ***22*** ***12*** *4.6-36*	**FM sweep a smooth curve** (i.e., no inflection), beginning steeply and then increasing in curvature*. May have a **well defined downward tail**. **Peak power of call typically persists for at least 1 ms on non–saturated calls.** Forage close to ground or vegetation. *some calls may have an inflection, but the smoothly curved variant is diagnostic.
	Myotis austro-riparius **south-eastern myotis**	***43.6*** ***45*** ***42*** 38-48	***84.3*** ***95*** ***73*** 66-116	***39.6*** ***41*** ***38*** 31-44	***46.4*** ***48*** ***44*** 42-65	***4.6*** ***5.5*** ***3.8*** 2.0-6.2	***17.6*** ***22*** ***13*** 5.9-31	***6.1*** ***8.6*** ***3.6*** 1.8-14	***6.6*** ***11*** ***2.2*** 0.0-22	***9.7*** ***15*** ***4.7*** 4.0-26	**FM sweep a smooth curve** (usually no inflection), beginning steeply and then increasing in curvature*. May have a **well defined downward tail**. **Peak power of call typically persists for at least 1 ms on non–saturated calls**.
	Myotis septen-trionalis **northern long-eared myotis**	***43.2*** ***47*** ***40*** 32-53	***104*** ***114*** ***95*** 60-12	***37.0*** ***42*** ***32*** 25-50	***51.3*** ***62*** ***41*** 37-95	***3.9*** ***4.6*** ***3.1*** 1.7-6.6	***24.2*** ***30*** ***18*** 8.5-55	***11.7*** ***16*** ***7.4*** 3.0-36	***13.1*** ***18*** ***8.0*** 0.0-37	***18.6*** ***24*** ***14*** 6.5-43	**Calls may have up to 100 kHz of bandwidth.** FM sweep may be nearly linear making f_c difficult to recognize. Quiet but consistent calls. Fly near vegetation, often with a linear flight path when searching.
	Myotis sodalis **Indiana bat**	***40.8*** ***42*** ***39*** 34-47	***80.9*** ***90*** ***72*** 50-115	***37.5*** ***40*** ***35*** 25-43	***44.0*** ***47*** ***41*** 37-70	***5.8*** ***6.6*** ***5.0*** 1.9-7.8	***16.8*** ***21*** ***13*** 4.1-42	***4.6*** ***5.8*** ***3.3*** 1.0-16	***2.6*** ***4.6*** ***0.5*** 0.0-14	***7.1*** ***9.2*** ***5.1*** 2.3-23	Distinctive longer call type (>4.5 ms) may have a **secondary inflection leading into a "ledge" or flat section <1.3 ms** just prior to terminal sweep or "tail." Note: some Mylu long calls share this feature. Distinctive shorter call type also has ending ledge, but ~5–15% of shorter Myle & Mylu also exhibit this feature.
	Myotis lucifugus **little brown bat**	***39.7*** ***41*** ***38*** 34-46	***69.4*** ***78*** ***61*** 47-104	***36.5*** ***38*** ***35*** 27-43	***43.4*** ***47*** ***40*** 38-73	***5.8*** ***6.7*** ***4.9*** 2.0-7.8	***10.5*** ***14*** ***6.7*** 3.0-37	***3.5*** ***4.6*** ***2.3*** 1.0-15	***4.1*** ***6.2*** ***2.0*** 0.0-17	***5.0*** ***6.7*** ***3.4*** 2.2-23	Sometimes with multiple power centers making calls look clumpy. **Longer duration calls recorded in open air are more discriminating**. **Dur >7 and Lwr slp <3 distinctive.**

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	species	f_c	hi f	lo f	f_{maxE}	dur	uppr slp	lwr slp	slp @Fc	total slp	special characteristics
40 nonMyotiS	***Perimyotis subflavus*** **Tri-colored bat**	***42.6*** ***44*** ***41*** 36-47	***57.6*** ***67*** ***48*** 41-106	***41.3*** ***43*** ***40*** 34-46	***43.9*** ***46*** ***42*** 36-50	***7.1*** ***8.4*** ***5.8*** 3.5-12	***7.7*** ***14*** ***1.7*** 0.3-38	***1.1*** ***1.7*** ***0.4*** 0.0-4.9	***0.2*** ***0.7*** ***-0.4*** 0.0-4.2	***2.5*** ***4.0*** ***0.9*** 0.1-12	**Strongly inflected, almost vertical FM changing to low slope below 47 kHz for the majority of the call.** Calls generally consistent across a sequence. Appear hockey stick–shaped in sonogram when FM sweep is present. Some calls exhibit **"squiggles."**
	Lasiurus borealis **Eastern Red Bat**	***40.4*** ***44*** ***37*** 29-49	***67.6*** ***81*** ***54*** 29-99	***40.2*** ***43*** ***37*** 28-48	***43.8*** ***49*** ***39*** 29-73	***6.8*** ***9.1*** ***4.6*** 3.2-16	***10.0*** ***16*** ***4.4*** 0.1-25	***2.0*** ***3.2*** ***0.7*** 0.0-10	***0.6*** ***1.6*** ***-0.4*** 0.0-8.1	***4.4*** ***7.1*** ***1.7*** 0.1-17	**U-shaped calls; up–turn at end of call; may exhibit variable f_c across sequence. Power smoothly centered in call.** Low frequency can go as low as 30 kHz.
	Lasiurus seminolus **Seminole bat**	***40.4*** ***44*** ***36*** 33-49	***62.8*** ***76*** ***50*** 38-87	***39.9*** ***44*** ***36*** 36-44	***42.8*** ***48*** ***37*** 35-52	***7.6*** ***9.7*** ***5.5*** 4.9-11	***7.9*** ***13*** ***3.0*** 0.7-17	***1.5*** ***2.4*** ***0.6*** 0.4-3.5	***0.4*** ***0.9*** ***-0.2*** 0.0-2.3	***3.3*** ***5.3*** ***1.3*** 0.6-8.4	**(In progress) U-shaped calls; up–turn at end of call; may exhibit variable f_c across sequence. Power smoothly centered in call.** Low frequency can go as low as 30 kHz. Possibly acoustically indistinguishable from *L. borealis*.
	Nycticeius humeralis **Evening bat**	***37.8*** ***40*** ***36*** 31-43	***63.0*** ***78*** ***48*** 35-101	***36.1*** ***38*** ***34*** 28-43	***40.0*** ***43*** ***37*** 32-48	***6.6*** ***9.4*** ***3.8*** 3.3-14	***12.5*** ***20*** ***4.7*** 0.5-32	***2.3*** ***3.7*** ***0.9*** 0.0-6.1	***1.2*** ***2.5*** ***0.0*** 0.0-6.5	***4.9*** ***7.9*** ***1.8*** 0.1-13	Sweeping curved calls that may lack any inflection. Calls have more slope in body (lower slope) than do similar-shaped shorter and longer Pisu calls. **Sequences may display f_c alternating up and down.**

How to use this table

This table presents ranges for the general characterizing call parameters of echolocation calls. The boldface numbers display the mean and ± standard deviation of the subset of calls correctly identified using SonoBat automated classification, i.e., the subset of each species call repertoire having the most species-discriminating characteristics, using the default 0.90 discriminant probability threshold. The lower, smaller font numbers display the overall range of all calls in the library of species-known calls used to prepare the SonoBat classifiers. Bold text indicates the most species–discriminating characteristics.

Because of intraspecific variablity and similarity with other species, the parameters presented here will often be insufficient for confident identification. SonoBat extracts more than five dozen parameters that it uses for call and sequence classification.

Analyze 1) well–formed calls, i.e., search phase calls recorded from bats in a steady mode of flight, away from roosts and not accelerating or performing some other maneuver that elicits rapid, short calls, e.g., like that from a hand–released bat, and 2) calls with a strong signal that clearly rise above the background noise level and have little distortion or echoes. It is generally preferable to avoid analyzing calls that saturate, i.e., overload, the detector or recorder. However, saturated call specimens may still be used to interpret time-frequency characteristics, but consider the time-amplitude domain from saturated calls to be unreliable.

Terminology and key

lo f: lowest apparent frequency (kHz), **hi f**: highest apparent frequency (kHz); this can vary depending upon the distance to the bat, **f_c**: characteristic frequency, i.e., the frequency of the call at its lowest slope toward the end of the call, or the lowest frequency for consistent FM sweeps (kHz), **f_{maxE}**: the frequency with the greatest power (kHz), **dur**: call duration from the beginning to the end of the call (ms), **upper**: the slope of the upper portion or onset of the call (kHz/ms) from the high f to the knee (listed as HiFtoKnSlope on SonoBat output), **lower**: the slope of the lower portion or body of the call (kHz/ms) from the knee to the f_c (listed as KnToFcSlope on SonoBat output).

FM: frequency modulation, i.e., a change in frequency with time, **flat**: a call or portion of a call with a very low slope or no slope (horizontal), **inflection**: a pronounced change in the slope of a call, sometimes called a "knee," **power**: the amplitude or sound energy of a call or portions of a call, **squiggle**: an S-shaped variation in frequency with time over a portion of the call.

Echolocation Call Characteristics of Eastern US Bats

	species	f_c	hi f	lo f	f_{maxE}	dur	uppr slp	lwr slp	slp @Fc	total slp	special characteristics
30	***Lasiurus intermedius*** **northern yellow bat**	***28.4*** ***30*** ***27*** 33-25	***45.5*** ***53*** ***38*** 29-79	***27.9*** ***29*** ***26*** 25-32	***29.4*** ***32*** ***27*** 25-41	***10.5*** ***13*** ***8.3*** 3.7-16	***4.9*** ***7.3*** ***2.4*** 0.5-14	***0.9*** ***1.4*** ***0.4*** 0.2-2.9	***0.06*** ***0.3*** ***0.0*** 0.0-2.4	***1.9*** ***2.9*** ***0.9*** 0.3-6.0	**U-shaped calls; up–turn at end of call; may exhibit variable f_c across sequence. Power smoothly centered in call.** Low frequency can go as low as 25 kHz. Calls similar in shape and variability to other Lasiurans, but intermediate in frequency range between Labo/Lase and Laci.
	Eptesicus fuscus **big brown bat**	***27.9*** ***30*** ***26*** 21-33	***49.4*** ***56*** ***42*** 29-69	***26.5*** ***28*** ***25*** 19-32	***30.0*** ***32*** ***28*** 22-42	***8.2*** ***11*** ***5.3*** 2.8-19	***5.8*** ***8.3*** ***3.3*** 0.9-17	***1.8*** ***2.9*** ***0.7*** 0.2-9.4	***1.5*** ***2.9*** ***0.1*** 0.0-8.2	***3.1*** ***4.6*** ***1.5*** 0.3-12	Variable; calls with high f below 60 kHz can be confused with Lano and/or Tabr. **Calls with high f above 65 kHz distinguish from Lano**, even long calls have some FM component, i.e. never flat. The end of calls may hook upward. *** Shorter calls recorded with full detail, i.e., ones that closely approached the microphone, as indicated by the presence of harmonics, exceed 65-70 kHz.**
	Lasio-nycteris noctivagans **silver–haired bat**	***26.6*** ***28*** ***25*** 23-31	***41.7*** ***51*** ***33*** 26-63	***25.4*** ***27*** ***24*** 14-30	***28.8*** ***31*** ***27*** 24-44	***8.9*** ***13*** ***4.8*** 2.3-24	***5.5*** ***9.3*** ***1.7*** 0.0-22	***1.3*** ***2.7*** ***0.0*** 0.0-8.8	***1.1*** ***2.6*** ***-0.5*** 0.0-8.3	***2.6*** ***4.9*** ***0.4*** 0.0-12	Shorter calls reverse J–shaped; often with a distinct inflection. Some call variants can be confused with Epfu and/or Tabr. **Flat calls ≥26 kHz diagnostic.** Flat Laci calls are lower in f. Low slope calls in the 25–26 kHz range may be distinguished from Laci by the presence of an inflection. Epfu has more FM, typically with smooth curvature (no inflection). *** Shorter calls recorded with full detail, i.e., ones that closely approached the microphone, as indicated by the presence of harmonics, still do not exceed 50-55 kHz.**

Caveats: Please note that the range of characteristics listed in this table overlap among many of the species, and that although compiled from over 11,000 calls, it still represents a finite, noninclusive data set and any individual bat may emit calls beyond the typical ranges and call characteristics listed in this table (and mimic another species). This and the variability of bat echolocation calls renders acoustic classification of bats a probabilistic process and relatively inexact compared to a process like genotyping. For some species, confident species classification can only be achieved on a subset of call types within its repertoire that falls outside of data space shared with another species. As a result many recordings will have ambiguous species classification. Expect that, and seek the most species-discriminating call types on which to make species determinations.

Species classification also depends upon accurate extraction of call parameter data, and that depends upon high quality recordings having clear signals with a high signal to noise ratio and free from distortion and confounding echoes.

Echolocation Call Characteristics of Eastern US Bats

	species	f_c	hi f	lo f	f_{maxE}	dur	uppr slp	lwr slp	slp @Fc	total slp	special characteristics
20	***Corynorhinus townsendii*** **Townsend's big–eared bat**	***23.4*** ***26*** ***21*** 18-32	***42.5*** ***45*** ***40*** 36-51	***21.4*** ***23*** ***19*** 17-30	***31.1*** ***34*** ***28*** 22-41	***4.6*** ***6.3*** ***3.0*** 1.7-11	***7.1*** ***13*** ***1.2*** 0.2-70	***4.9*** ***6.6*** ***3.2*** 1.1-13	***4.2*** ***6.5*** ***1.9*** 0.0-13	***5.0*** ***6.5*** ***3.5*** 1.0-11	Low intensity, difficult to detect; harmonics often present. Call–shape **simple linear FM sweep**, (sometimes with upsweep at onset). *f*max may alternate between fundamental and second harmonic. This species sometimes applies more amplitude in the second harmonic than in the first.
	Cornorhinus rafinesquii **Rafinesque's big–eared bat**	***22.8*** ***25*** ***20*** 23-23	***39.8*** ***42*** ***37*** 40-40	***22.5*** ***25*** ***20*** 22-22	***33.2*** ***37*** ***30*** 33-33	***2.6*** ***5.1*** ***0.1*** 2.6-2.6	***6.2*** ***8.6*** ***3.7*** 6.2-6.2	***7.4*** ***8.9*** ***5.9*** 7.4-7.4	***6.7*** ***8.9*** ***4.4*** 6.7-6.7	***6.7*** ***8.1*** ***5.2*** 6.7-6.7	Low intensity, difficult to detect; harmonics often present. Call–shape **simple linear FM sweep**, (sometimes with upsweep or flat tone at onset before sweeping downward). *f*max may alternate between fundamental and second harmonic. This species sometimes applies more amplitude in the second harmonic than in the first.
	Tadarida brasiliensis **free–tailed bat**	***25.5*** ***28*** ***23*** 18-33	***32.3*** ***39*** ***25*** 19-61	***24.1*** ***26*** ***22*** 17-33	***28.0*** ***31*** ***25*** 18-46	***11.5*** ***14*** ***9.5*** 3.5-20	***1.6*** ***3.2*** ***0.0*** 0.0-17	***0.5*** ***0.8*** ***0.1*** 0.0-4.5	***0.4*** ***1.0*** ***-0.3*** 0.0-4.1	***0.7*** ***1.4*** ***0.0*** 0.0-4.8	Variable; FM to flat; can be confused with Epfu, Lano, or Laci. **Long calls that "turn on" power rapidly with high energy at beginning (oscillogram carrot–like).** Calls often **upswing into call and downswing** out of call.
	Lasiurus cinereus **hoary bat**	***20.1*** ***22*** ***18*** 16-32	***26.0*** ***31*** ***21*** 17-58	***19.7*** ***22*** ***18*** 16-31	***20.8*** ***23*** ***18*** 17-49	***11.0*** ***15*** ***7*** 4-26	***2.2*** ***4.1*** ***0.3*** 0.1-14	***0.4*** ***0.8*** ***0.1*** 0.0-5.7	***0.0*** ***0.2*** ***-0.1*** 0.0-4.6	***0.7*** ***1.4*** ***0.1*** 0.0-8.3	**Pronounced or subtle U–shape;** very flat calls may have slight downturn into call or upturn at end. Fully formed (i.e., good quality) calls never get completely flat like a Tabr or Lano, but out of range fragments can appear flat and mimic Tabr. The most flat calls tend to be lower in f than flat Lano calls. **Low f may vary across sequence**, **power builds toward center then gradually declines**. Short calls can be confused with Lano, Epfu, or Tabr.

Sources:

Characteristics gleaned from recordings acquired by J.M. Szewczak, Humboldt State University Bat Lab (J.M. Szewczak, Aaron Corcoran, and Jean-Paul Kennedy), Patricial C. Ormsbee, USFS Pacific Northwest Research Station, and various contibutors to the Pacific Northwest Bat Grid, T.J. Weller, USFS Redwood Sciences Lab, and numerous other generous contributors.

The information presented in the table represents work in progress and is presented with the acknowledgement that it is unlikely to be the definitive description of these species' acoustic characteristics. Please use accordingly.