QUALITATIVE IDENTIFICATION OF FREE-FLYING BATS USING THE ANABAT DETECTOR

MICHAEL J. O'FARRELL, BRUCE W. MILLER, AND WILLIAM L. GANNON

O'Farrell Biological Consulting, 2912 North Jones Boulevard, Las Vegas, NV 89108 (MO'F)
Wildlife Conservation Society, 185th and Southern Boulevard, Bronx, NY 10460 (BWM)
Museum of Southwestern Biology, University of New Mexico, Albuquerque, NM 87131 (WLG)

A variety of ultrasonic (bat) detectors have been used over the past 3 decades to identify free-flying bats. Analyses of recorded echolocation calls were slow and typically restricted to few calls and at a resolution obscuring details of call structure. The Anabat II detector and associated zero-crossings analysis system allows an immediate examination, via a laptop computer, of the time-frequency structure of calls as they are detected. These calls can be stored on the hard drive for later examination, editing, and measurement. Many North American bats can be identified to species by qualitatively using certain structural characteristics of calls, primarily approximate maximum and minimum frequencies and morphological aspects of calls (e.g., linearity and changes in slope). To identify calls precisely, it is important to use a continuous sequence of calls from an individual in normal flight rather than from single isolated calls. All calls are not equally useful, and many fragmentary calls must be discarded before making a determination. Each sequence of calls must be examined to ensure that multiple bats have not been simultaneously recorded, which confounds correct identification. We found the percentage of non-usable calls within usable vocal sequences to be highest in vespertilionids (20–40%), whereas for other families this was frequently <10%. Active rather than passive collection of data maximizes quality and quantity of diagnostic calls and provides a contextual base for the investigator.

Key words: Chiroptera, bats, echolocation, vocal signatures, identification, technique, Anabat

For >30 years, an array of ultrasonic (bat) detectors has been developed to allow investigators to hear and visualize the echolocation calls of bats (Fenton, 1988; Kunz et al., 1996). Echolocation calls of many species of bats appear distinctive (Simmons et al., 1979), prompting efforts to distinguish among species of free-flying bats. A common approach involves use of a narrowband, heterodyne unit tuned to specific ranges in frequency (Ahlén, 1990). This is particularly effective when dealing with bats that use calls with a constant-frequency component, relying on a combination of auditory discrimination by the observer and the use of specific tuned frequencies deemed most useful. In addition, broadband detectors have been used widely to obtain the time-frequency structure of calls for identification of species (Barclay, 1983; Fenton and Bell, 1981; Kalko, 1995; O'Farrell, 1997). Species-specific calls, however, generally have been portrayed as single, or a few, representative calls at low resolution (Fenton and Bell, 1981).

The recent development of the Anabat II detector (Titley Electronics, Ballina, New South Wales, Australia), using a zero-crossings analysis interface module (ZCAIM) and Anabat5 and Analook software, brings a new dimension to identification of free-flying bats in the field. Unlike previous systems, Anabat can be connected directly to a laptop computer and the time-frequency display of calls can be seen in greater clarity (on a 21.5 by 16 cm screen rather than on the small portable oscilloscopes with a screen of ca. 5 by 4 cm used in earlier stud-

ies). Although Anabat can be coupled to an inexpensive tape recorder, connection directly to a laptop avoids distortion and background noise. Incoming calls can be evaluated, echoes and other noise can be eliminated by adjustment of sensitivity, and clean calls can be saved as digital computer files, <25 kilobytes in size, and named with a year-date-time code. The greatest difference between Anabat and earlier zero-crossings systems is that it is possible to examine instantaneously a single sequence containing numerous calls, usually on a single screen, by automatic compression of the time between calls. Anabat provides an examination of structural detail not readily available with other systems.

Over the past 4 years, we examined calls of bats throughout the southwestern United States and Belize, Central America. We found that bats that produce calls of sufficient intensity to be detected can be identified readily using qualitative criteria. At present, we believe that attempts to distinguish species statistically using select measurements may be misleading and actually lessen the ability for identification. Biologists studying tropical birds recognize that it is essential to be able to identify birds by their sounds and have the skill to make recordings of their voices (Parker, 1991). Guidance on use of the equipment is often necessary and determines the usefulness of the recordings (Budney and Grotke, 1997; Gulledge, 1976; Kroodsma et al., 1996; Ranft, 1991; Wickstrom, 1982). We found that techniques of using the Anabat system can affect the accuracy of species determinations and quantity of usable vocal signatures collected. Our purpose is to describe the qualitative procedure and structural characteristics that we use to identify species of free-flying bats using the Anabat system. Techniques described in this paper were developed from a regional sampling that allowed examination and determination of the vocal signatures from >50 species of bats within five families. However, for the purpose of this paper, only a few representative taxa have been selected to illustrate our methodology.

Materials and Methods

Fifty-nine locations in the southwestern United States (California, 1; Utah, 1; Wyoming, 1; Nevada, 3; Arizona, 16; New Mexico, 37) were sampled for bats from May 1994 through August 1995. We also sampled at nine major locations in Belize from February 1995 through July 1996. An attempt was made to sample the available range of elevations and associated habitats. Our aim was to examine the greatest number of species to furnish the methodological basis for establishing vocal signatures of bats. At each site, echolocating bats were monitored with an Anabat II detector linked either through the ZCAIM to an IBM-compatible laptop computer running Anabat5 software or directly to a cassette recorder (CTR-76, Tandy Corporation, Fort Worth, TX). Tape recordings were transferred to the computer at a later time using the ZCAIM and Anabat5 software. Simultaneous with acoustic sampling, we used mist nets and harp traps to collect a representative sample of bats.

Acoustic sampling entailed monitoring forest trails, habitat edges, streams, ponds, roosts, and other areas that we suspected would have concentrated bat activity. During such sampling, the computer was monitored to maximize the likelihood of saving high-quality calls. Sensitivity adjustments were made to minimize or eliminate echoes, enhancing morphological characteristics of calls used to identify species. Likewise, orienting the detector to follow the flight path of a target bat and attempting to move the detector closer to active bats provided greater numbers of useful sequences of calls. Concomitant decisions were made to save representative samples of vocal sequences that visually appeared to be associated with various behaviors (e.g., search, pursuit, and capture).

We defined a call as an individual, discrete vocal pulse. Each call had a frequency range (maximum and minimum frequency), a duration (time in milliseconds from the beginning to the end of a call), and a shape (ranging from slightly curvilinear to distinctly bilinear with some incorporating constant-frequency components). A series of consecutive calls produced by a single individual in a single pass comprised a sequence.

We identified the source of specific vocaliza-

tions in several ways. Visual recognition was occasionally possible by illuminating free-flying individuals with a hand-held spotlight during acoustic monitoring. Some vocalizing individuals were followed acoustically into a net or trap and identification obtained immediately. When possible, acoustic sampling was conducted outside known roosts to follow a known species immediately upon evening dispersal. To avoid flight-initiation calls, recording was done at distances >15 m from the exit to a roost.

In addition, captured animals were released individually, under controlled conditions after activity declined, so they could be monitored without extraneous input from other bats. Some released individuals were recorded after affixing a temporary, chemical light-emitting tag (Minilight Sticks, Chemical Light, Inc., Wheeling, IL) to the fur, either dorsally or ventrally. In Belize, emballonurid, mormoopid, and uncommon vespertilionid bats were released in a solid-ceiling, lathe-sided enclosure (12.5 by 6.75 m), and recordings were obtained for known individuals flying unrestrained within the enclosure.

Calls recorded from known species were cataloged for a reference library. All saved files were compared visually with known cataloged calls. As we gained experience, we continually re-examined and compared all archived files. Basic aspects of call structure, including maximum and minimum frequency, duration, and shape were used to identify species qualitatively. Although minimum and maximum frequency and duration are parameters that can be measured precisely, we claim a qualitative approach because we used visual approximations of each for identifying species. We initially used Anabat5 software for visual examination but switched to the more recent Analook software. Although Anabat5 is the software necessary for recording calls, the resolution of frequency is limited (e.g., 0–40 kHz, 0–80 kHz, or 0–160 kHz), and the scale is linear. Analook uses a logarithmic display of frequency (0–200 kHz), with appropriate lines of reference, and more sophisticated measuring capabilities than Anabat5. We used Analook to evaluate minimum and maximum frequency and duration of calls to assess the utility of using those measures compared with qualitative judgments.

To assess our ability to identify species using our qualitative procedures, two types of tests were formulated using bats from the southwestern United States. One of us (M. J. O'Farrell) developed test 1, which incorporated calls of 18 species. Test 1 contained 48 files, each species represented by from one to four files. Files were selected and edited based on the following criteria: only a single species was represented; sequences containing only a few calls were avoided; sequences contained at least some calls considered representative of the species; and a few sequences, obtained from hand-released animals, were identified as such, because calls obtained this way tended to lack the full range of structure obtained from free-flying individuals. Test 2 (developed by W. L. Gannon) contained 65 files of 13 species of bats. Each file in test 2 contained multiple bats of the same species or different species. The emphasis of test 2 was to simulate field recordings by providing a context of multiple sequences and individuals, unlike test 1 that emphasized a single sequence of a single species. All files comprising each test had identifying information removed and were randomized and renamed by a third party. When taking each test, we knew the geographic region sampled and, hence, which species could have been recorded.

Results and Discussion

Shape, frequency, and duration.—We follow a stepwise procedure for evaluating and identifying species. Archived computer files of calls are scanned rapidly and are separated by appropriate structural characteristics. These may be minimum frequency, maximum frequency, general shape, or variability in these parameters, depending on the family of bats encountered. Not all characteristics are necessarily used at all times. Most species of bats in the southwestern United States (vespertilionids and molossids) can be separated initially by approximate minimum frequency. For example, we categorize species of *Myotis* as 50-, 40-, and 30-kHz bats, but the actual minimum frequencies for individual calls in a given sequence may vary over a range of 3–5 kHz.

There are usually several species that fall within each category, and these are separated by consistent differences in shape. For example, *Myotis yumanensis* and *M. cali-*

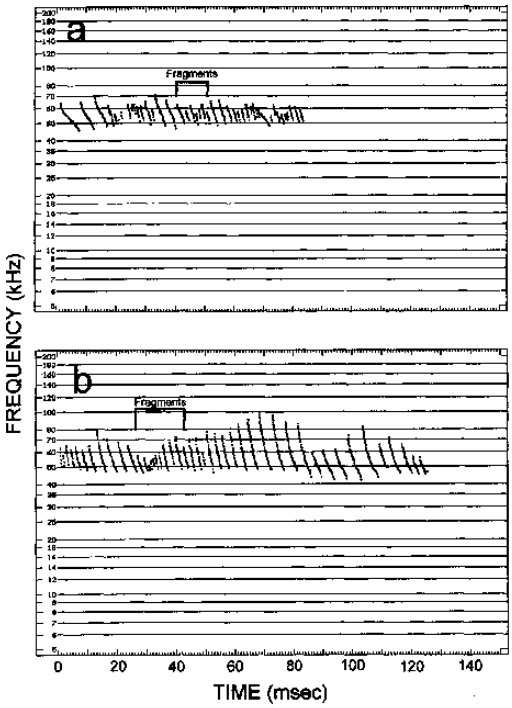

FIG. 1.—Frequency-time display (Analook software) of vocal sequences produced by a) *Myotis yumanensis* and b) *M. californicus* illustrating select fragments, calls with complete structure, and differences in shape for 50-kHz bats. The time between calls is compressed by the software to allow more calls per screen.

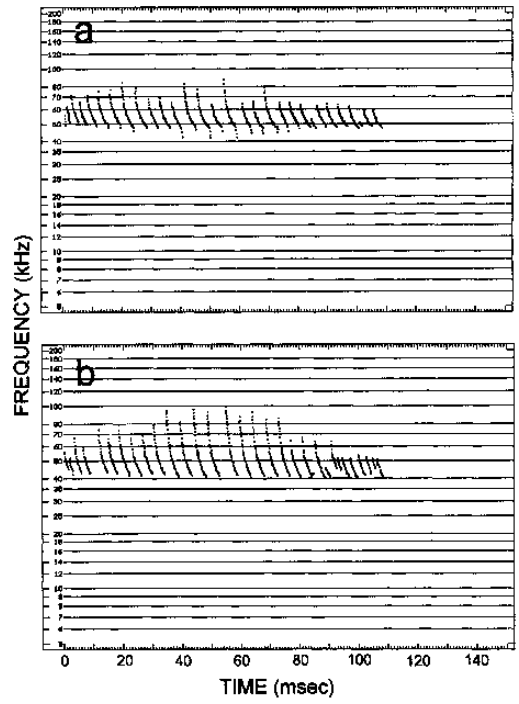

FIG. 2.—Frequency-time display (Analook software) of vocal sequences produced by a) *Myotis californicus* and b) *M. ciliolabrum* illustrating differences in minimum frequency for bats with calls of similar shape. The time between calls is compressed by the software to allow more calls per screen.

fornicus are similar in size and may occur syntopically, and both are 50-kHz bats (Fig. 1). Not all calls within a sequence of calls can be used for identification purposes. These unusable calls are fragmentary in nature and are caused by a variety of factors (e.g., distance and orientation of bat to the detector). However, there are distinct differences in the shape of calls that appear complete. Calls of *M. yumanensis* rarely exceed 70 kHz, are longer in duration, and have a distinctive "lazy S" shape (Fig. 1a). *M. californicus* calls approach and commonly exceed 100 kHz, are short in duration, and tend to be linear (Fig. 1b). Distinguishing between the species using a fragmentary call would be impossible, but collection and examination of full sequences of calls provide sufficient information for accurate identification. We stress that sequences in Fig. 1 and subsequent figures are representative of each species selected but do not represent the full range of variation observed.

Some species have calls with similar shapes but consistently different minimum frequencies (Fig. 2). We categorize *M. californicus* as a 50-kHz bat (Fig. 2a) and *M. ciliolabrum* as a 40-kHz species (Fig. 2b). The ease of separating these two species acoustically is particularly striking because they are so similar in external morphology that identification in hand is extremely difficult (Bogan, 1974). Our experience with eight species of *Myotis* in the southwestern United States and three species of *Myotis* in Belize indicates that those with similar min-

imum frequencies have distinctly different call shapes and those with similar call shapes have minimum frequencies that are consistently offset by 7–10 kHz. We believe that this trend will be consistent for other areas with multiple species of syntopic *Myotis.*

Although minimum frequency is an important point of reference for vespertilionids and molossids, other families have structural features of calls in which maximum frequency is more diagnostic. Species that contain a constant- or quasi-constant-frequency component (Kalko and Schnitzler, 1993) generally fall within this group. *Noctilio leporinus* produces calls with a uniform maximum frequency, even with a decrease in call duration during pursuit (Fig. 3a). The upward-sweeping calls of *Saccopteryx bilineata* also are best characterized by maximum frequency (Fig. 3b). In addition, *S. bilineata* illustrates the importance of cadence or rhythm in production of calls in a sequence. The paired and stepped nature of these calls is characteristic of the species (Barclay, 1983; Kalko, 1995; O'Farrell and Miller, 1997).

Some bats (e.g., tropical molossids) exhibit a wide range of frequency in stepped rhythmic calls (Fig. 4). In such cases, minimum and maximum frequencies can be used as diagnostic brackets. For example, search-phase calls of *Molossus sinaloae* range in frequency from 36 to 50 kHz (Fig. 4a), but those of *M. ater* range from 24 to 38 kHz (Fig. 4b). Secondarily, the general shape and duration of calls is important in distinguishing among such species. Calls of different species of *Pteronotus* have a common structural theme: an initial constant-frequency component; an intermediate, steep, downward sweep in frequency through time; and a terminal constant-frequency portion (O'Farrell and Miller, 1997). As with *Molossus,* identification of *Pteronotus* can be made using brackets of minimum and maximum frequency. *P. personatus* range from 83 to 68 kHz, and those of the syntopic congener, *P. davyi,* range

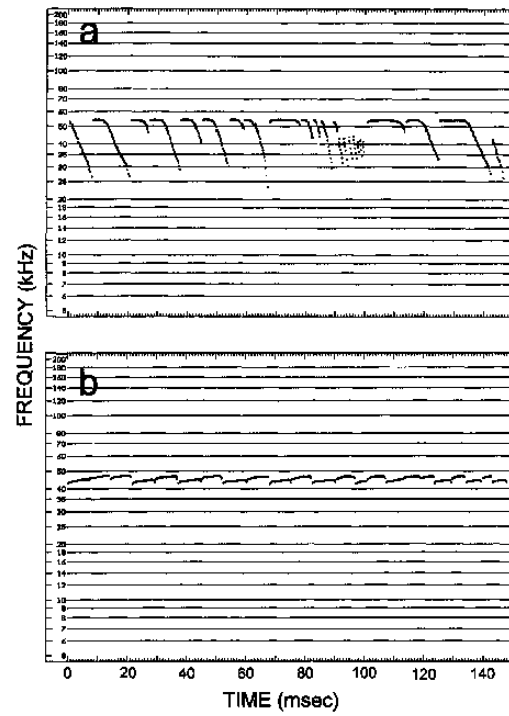

FIG. 3.—Frequency-time display (Analook software) of vocal sequences produced by a) *Noctilio leporinus* and b) *Saccopteryx bilineata* illustrating the diagnostic importance of maximum frequency. The time between calls is compressed by the software to allow more calls per screen.

from 68 to 58 kHz (O'Farrell and Miller, 1997). For bats with a long constant-frequency component (e.g., *P. parnellii*), maximum frequency equals the constant frequency and is diagnostic (O'Farrell and Miller, 1997).

General limits in range of frequency and shape of calls may reduce the identity of a bat to one of several species. In this case, the uniformity of calls in a sequence with respect to upper or lower limits of frequency can be used to separate species. Bilinear calls (i.e., calls with a distinct break in slope) of *Lasionycteris noctivagans* are consistently uniform (Fig. 5a). *Lasiurus cinereus,* in contrast, usually demonstrate calls that fluctuate in minimum frequency within a sequence (Fig. 5b), a pattern that

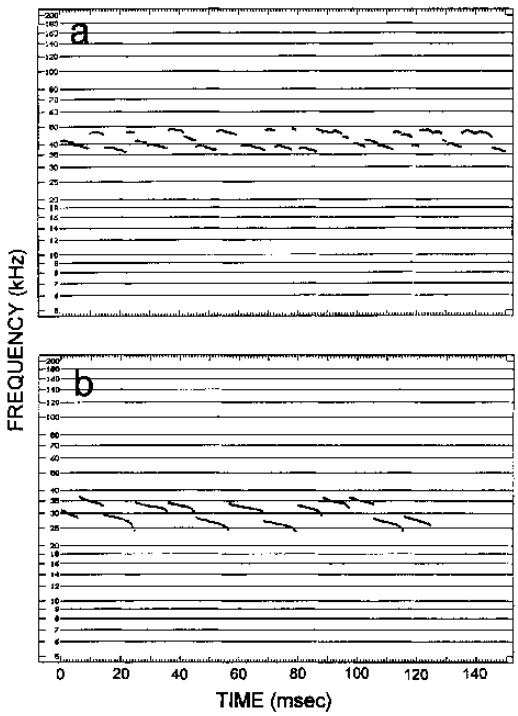

FIG. 4.—Frequency-time display (Analook software) of vocal sequences produced by a) *Molossus sinaloae* and b) *M. ater* illustrating differences between the brackets of maximum and minimum frequency. The time between calls is compressed by the software to allow more calls per screen.

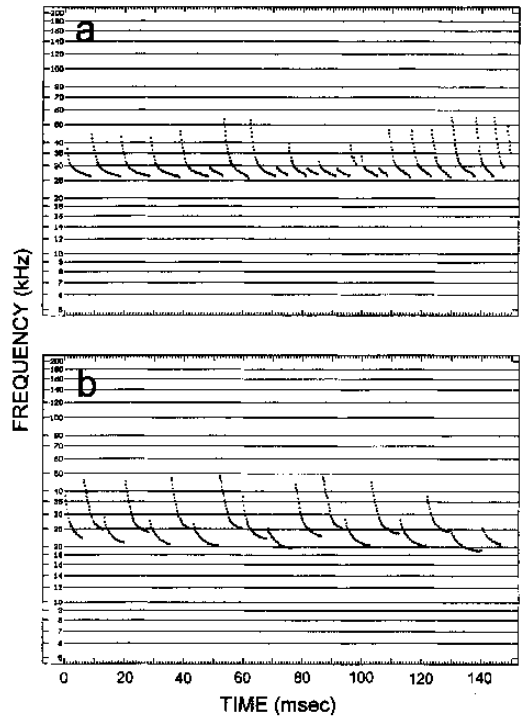

FIG. 5.—Frequency-time display (Analook software) of vocal sequences produced by a) *Lasionycteris noctivagans* and b) *Lasiurus cinereus* illustrating differences in sequential variability. The time between calls is compressed by the software to allow more calls per screen.

we have found for other members of the genus examined to date (i.e., *L. ega, L. borealis,* and *L. blossevillii*). Although individual, higher frequency calls of *L. cinereus* could be confused with *L. noctivagans,* uniformity of calls, or lack thereof, within a sequence allows separation of these species when a full sequence is examined. Without the context of a series of calls, accurate identification may not be possible.

While evaluating calls using the stepwise procedure, it is imperative to assess if calls detected are from the same individual or if they represent multiple bats. Calls from two individual *Tadarida brasiliensis* are shown in Fig. 6a. Although the shape of calls is different between the two individuals, the determination that two bats were responsible for the calls can only be verified by examination of the sequence at different time scales. Expanding the time scale (e.g., from 10-ms intervals to 500-ms intervals) in real time, as opposed to the available compressed mode, allows enough calls to be displayed to determine the cadence of incoming calls. The relationship of the time between calls remains relatively constant for an individual. However, the time between calls of one individual will change through time in relation to a second individual (Fig. 6a).

Situations with multiple individuals of different species also must be recognized for accurate identification of each species present. Two species with morphologically similar calls are illustrated in Fig. 6b. During search phase, *Eptesicus furinalis* has a

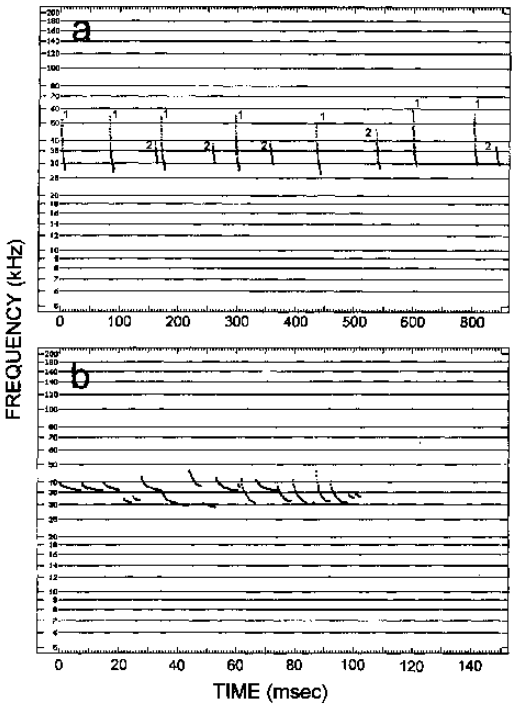

FIG. 6.—Frequency-time display (Analook software) of simultaneous vocal sequences produced by a) multiple *Tadarida brasiliensis* (1 and 2 distinguish each individual) and b) *Eptesicus furinalis* (minimum frequency ca. 35 kHz) and *Lasiurus ega* (minimum frequency ca. 30 kHz). The time between calls is compressed by the software to allow more calls per screen.

minimum frequency of ca. 35 kHz and that of *Lasiurus ega* ca. 30 kHz. Expansion of the time scale in real time will help determine presence of multiple individuals under more complex conditions than illustrated in Fig. 6b.

Variability of parameters.—A quantitative examination of minimum frequency, maximum frequency, and duration reveals large variation and overlap between some species (Table 1). Variation in frequency was greatest for maximum frequency in vespertilionids (CV = 13.4–24.7%) and minimum frequency for the noctilionid (25.9%). For the same families, the least variation was found for minimum frequency in vespertilionids (4.5–11.8%) and maximum frequency for the noctilionid (9.9%). The stepped nature of sequential calls in the emballonurid and tropical molossids resulted in low and relatively consistent variability for both minimum frequency (5.0%; 9.3–13.4%, respectively) and maximum frequency (4.5%; 9.9–16.3%, respectively). Calls of bats tend to vary in the range of frequencies from search through pursuit and capture of prey (Kalko and Schnitzler, 1993), and higher frequencies are attenuated more rapidly than lower frequencies. Thus, greater variation should be expected in maximum frequency.

Calls produced by bats of the genus *Pteronotus* exhibit the least variability of minimum frequency (0–0.25%) and maximum frequency (0–0.34%) of any species of bat we have examined (O'Farrell and Miller, 1997:959, Table 2). Within the genus, these characters are highly reliable indicators of species identity. We find that, even with single fragmentary calls, the different species of *Pteronotus* are distinguished easily.

Within the genus *Myotis,* means of minimum frequency were significantly different between species (Table 1), but the sample size (10 sequences of calls/species) was small and specifically excluded situations with multiple bats. Obrist (1995) found significant differences in minimum frequency for several species of vespertilionids when flying alone versus flying in conspecific groups. We found similar situations, with bats of several different families flying in conspecific groups. When multiple individuals are detected flying close to each other, calls of each individual shift minimum frequency several kHz from that of an adjacent individual—the differential among minimum frequencies increasing with an increasing number of individuals being sampled. Variability observed in minimum frequency of several conspecific individuals recorded while flying close together makes statistical separation of species difficult, but the species-specific shape of the calls remains diagnostic. Qualitative judgments must consider this source of variation, but

TABLE 1.—*Summary of mean measurements of calls (± 1 SD) of select species of bats from the western United Sates and Belize.*

Species	Location	n[a]	Maximum frequency (kHz)	Minimum frequency (kHz)	Duration (ms)
Myotis californicus	Arizona	171	79.9 ± 12.43	51.8 ± 2.74[b]	2.2 ± 0.62
	New Mexico	110	76.0 ± 10.89	48.5 ± 2.53	2.0 ± 0.50
Myotis ciliolabrum	Wyoming	231	62.4 ± 12.54	40.3 ± 2.36[b]	3.5 ± 1.44
	New Mexico	141	61.1 ± 10.28	39.2 ± 2.11	3.9 ± 1.05
Myotis yumanensis	Arizona	184	64.2 ± 8.47	47.7 ± 4.22[b]	3.2 ± 1.36
	New Mexico	142	69.5 ± 9.33	46.5 ± 2.10	3.2 ± 0.98
Lasionycteris noctivagans	Nevada	273	37.4 ± 9.31	26.3 ± 1.54	5.9 ± 2.30
	New Mexico	130	35.5 ± 8.12	25.5 ± 2.11	3.3 ± 1.90
Lasiurus cinereus	Arizona	180	30.8 ± 7.18	21.9 ± 2.36	8.2 ± 2.82
	New Mexico	190	40.8 ± 7.03	22.0 ± 1.89	6.2 ± 3.11
Saccopteryx bilineata	Belize	263	47.0 ± 2.35	45.1 ± 2.02	6.1 ± 1.58
Noctilio leporinus	Belize	136	51.2 ± 5.06	40.7 ± 10.54	7.0 ± 3.62
Eptesicus furinalis	Belize	221	52.6 ± 8.61	37.5 ± 1.13	5.5 ± 1.58
Lasiurus ega	Belize	160	43.0 ± 8.64	32.0 ± 2.45	6.6 ± 2.73
Molossus ater	Belize	138	30.8 ± 4.29	27.2 ± 4.43	11.6 ± 3.68
Molossus molossus	Belize	80	33.9 ± 4.52	30.3 ± 4.76	9.3 ± 2.97
Molossus sinaloae	Belize	168	41.6 ± 3.88	39.6 ± 3.92	6.2 ± 2.46

[a] n = the number of calls from 10 separate echolocation sequences. Independent two-tailed hypotheses ($d.f.$ = 18), H_0: $\mu_1 = \mu_2$, were tested by a two sample t-test of minimum frequencies for *Myotis californicus* compared with those of the other two *Myotis*.
[b] $P < 0.001$

shapes of calls will help resolve identification. When examining fragmentary calls, overlap in minimum frequency can occur between species such as *M. californicus* and *M. yumanensis*. However, it is possible to separate groups (e.g., species of *Myotis*) qualitatively by the range of approximate minimum frequency.

Duration of calls, for all species examined (Table 1) exhibited the greatest variation (CV = 25.1–57.6%). Obrist (1995) found similar variation in duration but noted the reverse trend for minimum and maximum frequency. Duration has been used as a descriptor of calls (Ahlén, 1990; Fenton and Bell, 1981; Novick, 1971; Waters and Jones, 1995). However, duration changes as bats progress from search phase, through detection of a target, and pursuit of prey (Griffin et al., 1960; Novick, 1963, Schnitzler and Henson, 1980; Simmons et al., 1979). We feel that duration is of value for distinguishing among species only when using search-phase calls produced under conditions of negligible clutter. Bats that are active near clutter have calls that are significantly shorter in duration than those flying in the open (Faure and Barclay, 1994; Kalko and Schnitzler, 1993).

Qualitative versus quantitative approaches.—Quantification was not necessary for identification and, in fact, could be misleading, particularly with fragments that overlap in range between species. We used approximate limits of the frequency range and a visual assessment of shape. Although some will be uncomfortable with the use of such a qualitative approach to identification of vocal signatures of bats, the procedure is analogous to auditory identification of birds and anurans. One of us (B. W. Miller) has spent 10 years in Belize using calls and songs during avian surveys, in which a large percentage of species rarely are seen and customarily identified only by vocalizations. For birds, no quantification of calls or song is needed for field identification of species. In neotropical forests, qualitative identification of avian vocalizations is not only an essential technique (Parker, 1991), but virtually all field guides to neotropical birds (Edwards, 1989; Howell and Webb,

1995; Peterson and Chalif, 1973; Ridgely and Gwynne, 1989; Stiles and Skutch, 1989) provided qualitative descriptions of vocalizations to aid in discriminating among species. The same holds true for field guides for other regions of the world. Anuran vocalizations also are qualitatively used by herpetologists to identify species (Zimmerman, 1994).

Caveats.—Care must be taken when establishing a library of calls from known species. Although we obtained calls from some animals flying in enclosures, it is a technique that works for only some species and despite its limitations, it may be a necessary technique when dealing with rare species. Other techniques used to record vocalizations of a known species do not work under all conditions. Bats emerging from a roost must be recorded far enough from the roost to eliminate background echoes from roost substrate and allow individuals to switch to the type of calls that are given when in free flight. Caution also must be exercised when evaluating calls obtained from handreleased bats. We find that hand-release is a valuable method for obtaining initial calls of known species, but many of these calls are of minimal value, generally being composed of fragmentary calls similar to those emitted from bats emerging from roosts. Likewise, our experience with light tags indicates that most individuals simply fly away, and few or no calls are obtained. However, when a tagged individual does remain in the vicinity, the technique is invaluable. Experimentation and flexibility in performing hand-releases, with or without light tags, is necessary to obtain usable calls.

As with recording birds for identification (Budney and Grotke, 1997), complete vocal sequences of bats will be of more use than small fragments, out of context, to learn the nuances of bat vocal signatures. The quality and usefulness of a sequence of calls will depend on the species under examination and the fragmentary nature of the calls. Species that show little interspecific variability in shape of calls (e.g., *Pteronotus*) may be identified with few, and even fragmentary, calls. Saving sequences to the computer rather than a tape recorder increases the quantity of usable calls. In New Mexico for example, 22 usable calls were gleaned from one 45-min tape recording and only two usable calls from a second, full 45-min tape. The uncontrolled nature of saving to tape accounts for the pattern of relatively few usable calls per unit of taping. Monitoring calls on the computer screen and selecting sequences improves the overall quality and quantity of calls to be evaluated, because only those sequences judged as usable are saved to the computer.

We calculated the percentage of calls that cannot be used for reliable identification within usable sequences saved directly to computer (Table 2). Vespertilionid sequences yielded a greater percentage of non-usable calls ($\bar{X}$ = 21.8%, range = 6.9–37.4%) than other families examined ($\bar{X}$ = 12.4%, range = 8.1–19.2%). Calls produced by *Lasiurus cinereus* tended to have more diagnostic structure, even in fragments, than other vespertilionids. Regional differences suggest that there is probably some investigator variability.

Variability of echolocation sequences is apparent when actively monitoring the computer screen during acoustic sampling. Calls change within and between sequences as the bat moves in relation to the position of the detector, changing proximity to a target or background clutter, and presence of other bats. These factors provide context that helps in evaluating calls for identification of species. Results of our performance on tests of acoustic identification suggest that context is important. W. L. Gannon scored 30 correct (62.5%) for test 1 and 59 correct (90.8%) for test 2. M. J. O'Farrell scored 43 correct (89.6%) for test 1 and 63 correct (96.9%) for test 2. We believe that taking our own tests is valid because of the preparation of the final test by a third party. We originally believed test 1 to be easier because of the care involved in

TABLE 2.—*Summary of the number of echolocation calls used for identification, those that could not be used, and the percent uncertainty of identification reflected by non-usable calls.*

Species		Number used	Number not used	Percentage
Myotis californicus	Arizona	171	89	34.2
	New Mexico	110	41	27.2
Myotis ciliolabrum	Arizona	231	88	27.6
	New Mexico	141	38	21.2
Myotis yumanensis	Arizona	184	76	29.2
	New Mexico	142	35	19.8
Lasionycteris noctivagans	Nevada	273	76	21.8
	New Mexico	130	41	24.0
Lasiurus cinereus	Arizona	180	17	8.6
	New Mexico	190	14	6.9
Saccopteryx bilineata	Belize	263	29	9.9
Noctilio leporinus	Belize	136	12	8.1
Eptesicus furinalis	Belize	221	132	37.4
Lasiurus ega	Belize	160	81	33.6
Molossus ater	Belize	138	13	8.6
Molossus molossus	Belize	80	19	19.2
Molossus sinaloae	Belize	168	32	16.0

selecting individual sequences. After taking both tests, it was apparent that files with a short sequence from a hand-released individual gave the most difficulty in correct identification. Test 2 provided more context, which improved the identification process. We recommend that recordings be reviewed and archived soon after collection to assist in notation and to maximize the retrieval of content.

We stress that not every individual call can be used to identify free-flying bats and, likewise, not all sequences are usable. To be most effective, data should not be collected exclusively in a passive manner. Setting the equipment at a fixed location generally is not as useful for species identification because reception of the detector is directional. Only those animals that fly within the detector's cone of reception will provide a call sequence of sufficient quantity and quality for identification of species. Presence of the investigator allows for immediate examination of incoming signals, adjustment of sensitivity to reduce echoes, and the ability to follow vocalizing bats with the detector to maximize the number of signals recorded in a given sequence. Passive data collection generally yields a wealth of call fragments, sufficient for defining activity but not necessarily for identification of species.

The question has been raised as to how much experience is needed to reach reliable conclusions. This equates to asking how much experience is needed to achieve fluency in a foreign language or ability to identify birds or frogs by voice. Some people may be capable of achieving fluency in under a year, whereas others may never achieve fluency. Most people will fall on a continuum between these extremes. Learning how to distinguish species is not unique to using Anabat. The time required will depend on the complexity of the fauna. For frogs, Zimmerman (1994) stated that if lists of species and tapes of calls are not available, it could take an entire season to learn the calls of a particular fauna. For tropical bird faunas with reference tapes available for most species, several years would be the norm to achieve minimal competency. Even with birds, it should be pointed out that not all birders are equal in the ability to identify correctly all species (Kepler and Scott, 1981). For us, minimal competency was reached in a single, intensive field season of collection and evaluation of recordings.

However, there has been an ongoing learning process, and there is no reason to believe this will not continue into the future. The more experience gained in evaluating recorded files of sequences, the better the intuitive feel for the inherent range of variation for each species within a given geographic area. We find it useful to review archives periodically because, with experience, we are able to recognize patterns that were not apparent when first collected. Basically, if the researcher knows the total assemblage of species expected for an area (e.g., bird, anuran, bat), they should be able to identify that particular suite of species with experience.

It has been suggested that qualitative methods work for birds because vocalizations are used for different purposes (i.e., communication versus orientation) and that bird songs lack the variation perceived for bats, implying that birds can be identified but perhaps not bats. Although in many families bird songs are stereotypical (Budney and Grotke, 1997), many are learned and complex with a great range of variation (Kroodsma, 1982). Within songbirds, dialects are a taxonomically widespread phenomenon (Mundinger, 1982), and such dialects can be confusing as one travels from one location to another. Numerous species of birds have initial notes that converge in structure to a relatively pure-tone form, and in the same species, the remainder of the song frequently is extremely variable (Richards, 1981). Because of tremendous geographic differences in songs and calls within a single species, no phonographic record or set of records has enough geographical treatment to solve all problems of identification. There are species of birds with songs or calls that are practically indistinguishable (Robbins and Stallcup, 1981).

At the qualitative level that we utilize, we do not find variation within a species to be overwhelming. At present, we have not observed geographic variation. Calls of *Lasiurus ega* from southern California appear identical to those in Belize. Likewise, *Myotis ciliolabrum* from southern New Mexico can be distinguished readily by the same call shape and frequency range found in those individuals from Wyoming. Experience can be gained only by spending time in the field actively recording and in the laboratory examining recorded files. As experience is gained, limits of variation for each species examined will become apparent.

Validity of using Anabat to identify free-flying bats has been questioned because of the potential for making incorrect identifications, implying that mistakes do not occur with capture techniques. Errors in identification are not new to field biology. Not all captured bats are identified correctly and not all voucher specimens in museums are identified correctly. For birds, observer bias and problems of identification are well-documented (Bart, 1985; Bart and Schoultz, 1984; Kepler and Scott, 1981). During a study on observer bias in conducting acoustical estimates of density about one-third of the birds were misidentified (Bart, 1985). Recognizing that the greatest source of error in avian surveys is that of observers who are unfamiliar with the species, songs, or habitat requirements, Robbins and Stallcup (1981) emphasized an awareness of the potential for misidentifications but not to discount the overall value of the techniques.

The future.—Acknowledgment of errors in identification has not hampered development of acoustical techniques for surveying birds. In a review of two acoustic tapes of New World nightbirds, Marshall et al. (1991) provided historical examples of early mistakes made in the identification of nocturnal birds. However, early avian recordings were circulated widely and were instrumental in recognizing errors in identification. Biologists then proceeded to make corrections. We see standardized recording of Anabat files providing a similar service. Files that contain either unidentified or misidentified species and are available for correction as more experience is gained are analogous to misidentified

voucher specimens held in museums that may be re-examined as additional taxonomic knowledge is gained. We maintain that after standardized methods are adopted for the recording, archiving, and displaying of chiropteran vocal signatures, they, like avian recordings (Hunn, 1992; Parker, 1991), will serve as acceptable vouchers. Correctly recorded Anabat files, deposited in an accessible library (e.g., http://biology.unm.edu/~msb/batcall.html), will provide voucher records for future review, even if the species is misidentified or unidentified files are collected in new geographic areas.

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