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Acoustic characteristics of the echolocation call of the disc-footed bat, *Eudiscopus denticulus* (Osgood, 1932) (Chiroptera, Vespertilionidae)

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Summary

The disc-footed bat *Eudiscopus denticulus* is a rarely encountered Southeast Asian species whose behaviour, ecology and echolocation characteristics are hardly known. As part of a biodiversity survey, echolocation calls of three specimens caught in Vietnam were recorded in a flight tent situation, and their echolocation call parameters are described herewith in detail. The call shape was found to be similar to the typical broadband frequency modulated signal with a narrowband part at the end of the call. Based on the call characteristics this species is predicted as an "edge and open space aerial forager". Our paper also describes a unique call type that has not been mentioned before in the literature. The echolocation call characteristics provided hereby will hopefully facilitate species recognition during acoustic surveys in Southeast Asia and contribute to the conservation of this presumably rare and localized species in the future.

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1. Introduction

To date, only a handful of specimens of the disc-footed bat (*Eudiscopus deticulus*, Vespertilionidae) were found in Southeast Asia and despite the fact that it was described 80 years ago, information on this species can be summarized in a few lines. Its echolocation behaviour, which would be particularly important to localize the species and get more information about its distribution and ecology, remained hardly known.

The species was described from Laos [1] and was later reported from Myanmar [2], Thailand [3] and Vietnam [4, 5]. Roosts were found inside bamboo stems [3], where the adhesive disk-like pads on the feet help to cling to the smooth surface [6]. Foraging individuals were reported over bamboo thickets and forest edges [5], but no further details about the species' ecology are available.

The parameters of echolocation calls are essential to identify a given species during acoustic surveys. The acoustic method is an essential tool in determining species distribution and guild structure and this technique is widely used in inventory and monitoring surveys, as well as in planning adequate management [7, 8]. Moreover, this method is an increasingly important and widespread technique in Southeast Asia, too [9, 10, 11, 12]. The structure of the calls also provides insight into the species' foraging habitat and feeding strategy [13], therefore the information about the echolocation calls can help to conduct targeted surveys to find a given species in the wild.

So far, only one study analysed the echolocation calls of *E. denticulus* [11]. The authors of the study provided information about two hand-released specimens of *E. denticulus* flying in a relatively cluttered environment. They categorized the echolocation call as broadband frequency modulated signal. They also provided time and frequency measurement data based on one call from each individual. However, they don't detail the variations and the dynamics of the call structure.

In the course of a biodiversity survey in Vietnam, the echolocation calls of three individuals were recorded in a flight tent. In this paper, we describe the echolocation calls of *E. denticulus* in detail, including information about the variability of the call parameters. We believe that our results are more informative and more useful than the results of the previous study [11], because, due to the larger space available, the flight tent situation provides more reliable data than hand releasing in a cluttered environment.

2. Material and methods

In the course of a biodiversity survey in Vietnam between 5th and 8th of October 2008 in Pu Huong Nature Reserve, Nghe An Province, Vietnam (19°20′12 N, 105°01′18 E,

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380 m), three individuals of disc-footed bats were caught in four-bank harp traps set across forest trails. After removing the bats from the harp trap, they were kept in canvas bags for a maximum of two hours before further analyses. Echolocation calls were recorded in a home-made 6x3x3 meters flight tent made of commercial mosquito net. After recording, the individuals were taken as voucher specimens and can be found in the Mammal Collection of the Hungarian Natural History Museum under the accession numbers 23030, 23052, 23057. The forearm length and the weight of the studied specimens were taken and their sex was determined (Table I).

The bat calls were recorded by a Pettersson D1000X ultrasound detector (Pettersson Elektronik AB) on a CF memory card while the animals were flying in the flight tent. The detector was held by a person sitting in the corner of the flight tent and was pointed toward the bat. The sampling frequency was set to 500 kHz in 16 bits quality. The recorded sound files were subsequently uploaded to a computer.

Altogether, 243 “common” echolocation calls were segmented with good signal-to- noise ratio. We have also found 5 calls showing a call shape different from the normal echolocation calls and we describe them herewith separately, referring to them as “unique” call type.

All the calls were displayed, segmented and manually measured (512 points length FFT, Hann window, 96% overlapping) with a self-written Matlab 7.0 (The Mathworks, Inc.) script. The start- and endpoint of the calls were defined at 15 dB higher than the actual background noise level based on the power spectrum. Frequency was measured at the start (F_{start}) and at the end (F_{end}) of each call, and also at the maximum energy (F_{maxE}). The frequency bandwidth (F_{BW}) was calculated as $F_{\mathrm{start}} - F_{\mathrm{end}}$, because the maximum frequency equals F_{start} and the minimum frequency equals F_{end} in case of this species' echolocation call. The duration of the call (T) and the pulse interval (the time interval between the start of two consecutive calls, PI) were also measured. The mean, the standard deviation, the minimum and maximum values as well as the lower and upper quartiles for each parameter were computed for each specimen. The second order means based on the 3 individuals' means were also calculated. The statistical computations were made by Statistica 8.0 (Statsoft, Inc.).

3. Results

Based on the recordings of the 3 individuals, altogether 243 echolocation calls were segmented. In general, every “common” echolocation call contained a broadband, downward frequency modulated (FM) part without strong harmonics. Most of the calls started and finished with narrowband FM parts. The maximum start frequency was found to be around 119 kHz, and the minimum end frequency was around 45 kHz. At the start of the echolocation call, the narrowband FM part was always relatively short. However, at the end of the calls, the length of the narrowband FM part showed a gradual change (Figure 1). The maximum energy was at 61.7 kHz in average, and it fell into the second half of the calls. The mean length of the echolocation calls was around 2 ms. The longest call was 3.25 ms long. As for the pulse interval, we didn't find a clear unimodal or bimodal distribution; most of the calls followed each other at intervals between 31.9 and 82.1 ms, based on the lower and upper quartiles (Table II).

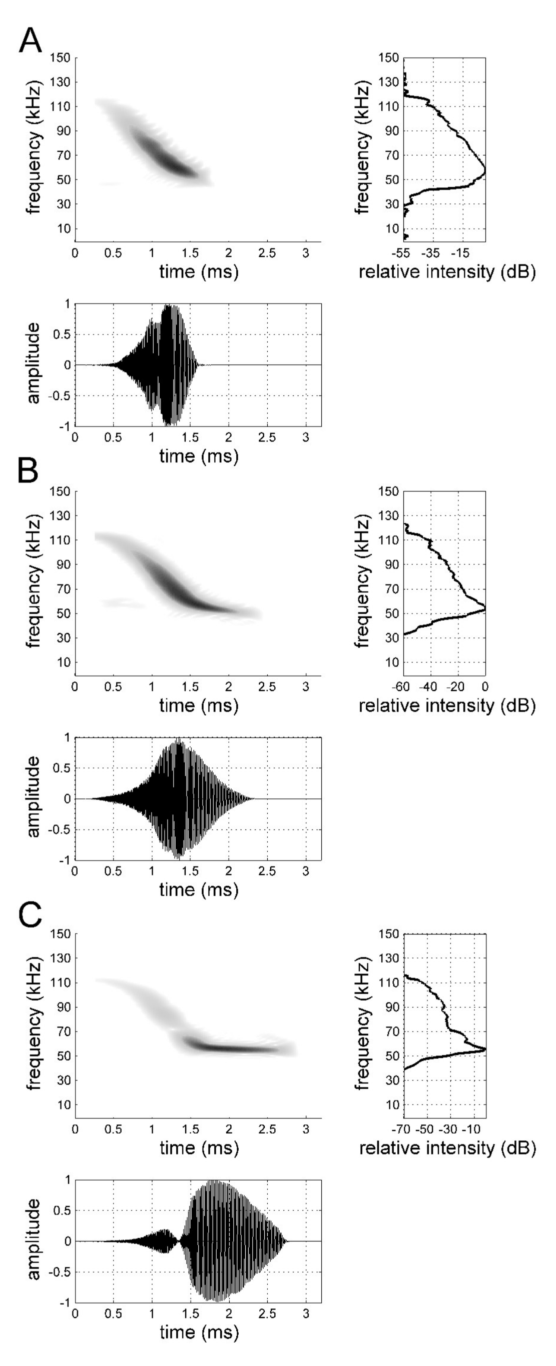

Figure 1. Three examples of the gradually changing echolocation calls in E. denticulus. The figure shows uppermost a call containing mainly broadband FM part (A), in the middle a call with short narrowband FM part (B) and a call with longer narrowband part (C) in the bottom. Each panel shows the spectrogram (left), oscillogram (bottom) and the spectrum (right).

In case of one individual (HNHM 23057), a “unique” call type was recorded 5 times (Figure 2). This faint upward frequency modulated call type always occurred right before the “common” echolocation call. The duration of this call type was 6.98 ± 1.98 ms ($N = 5$, ranging from 5.1 to 9.9 ms), and the pause between this one and the regular echolocation call was 3.78 ± 0.35 ms ($N = 5$, ranging from 3.6 to 4.4 ms). The frequency at the beginning was 70.5 ± 2.7 kHz ($N = 5$, ranging from 67.6 to 74.2 kHz), and it ended with 92.2 ± 1.6 kHz ($N = 5$, ranging from 89.8 to 93.8 kHz).

4. Discussion

The interpretation of the shape and the measured parameters of echolocation calls is important in acoustic identification and ecological niche prediction of bat species [13]. Although the sample size was limited in this study, we consider it important to publish these results, as the knowledge of echolocation call properties facilitates further research on distribution and ecology.

We assume that the echolocation and foraging behaviour of *E. denticulus* is similar to those of other bats using broadband FM signal with a narrowband FM end (also known as FM-CF bats, where the CF refers to constant frequency) [14]. In typical FM-CF bats, the narrowband FM part predominates in open habitat while the start frequency decreases. However, the narrowband FM part might totally disappear close to the clutter, while the start frequency increases. In a real world situation, if the above mentioned theory is valid for *E. denticulus*, it implies that in open space the starting frequency might be lower and the length of the final narrowband FM part might be longer than we observed within the frame of this study.

This call type and the changes in call shape seem stereotypical in the so called “edge and open space aerial forager” species [13], where the narrowband FM component is appropriate to detect flying target in more open space and the steep FM part is suitable for the localisation of prey items close to cluttered background. Thus, based on this call type, we predict that *E. denticulus* usually forages near the edges of clutter such as bushes and trees. This prediction agrees with the very few field observations on this species [5].

Despite the fact that the flight tent cannot serve as a model for all natural habitats, it is important to get such echolocation data from rare species (e.g. [15]). However, when interpreting echolocation call characteristics, we have to take into account that this artificial habitat is more similar to a cluttered natural habitat than to an open one [16]. Nevertheless, at the end of the calls, the narrowband frequency part shows a relatively large variability which means that the volume of the flight tent was enough for the bats to use echolocation calls for cluttered and for more open space, too. Hughes et al. [11] consider *E. denticulus* as a species using broadband FM echolocation call without a narrowband FM part. They admit that their recording situation was much more appropriate for recording echolocation calls that bats use in cluttered space. Our results show that in the flight tent the animals use calls with a narrowband FM part at the end of the calls. This difference between the results of the two studies can clearly be explained by the different recording situations: our recordings were made in a larger space.

We do not dare to assign any function to the “unique” call type as it was observed for only 5 times in one of the three studied specimens in an artificial environment. Nevertheless, in *Kerivoula pellucida*, a social call with a similar structure was described [17]. In this *Kerivoula* species, the social call starts with a quasi-constant frequency part at around 30 kHz and ends in an upward frequency modulated part at around 58 kHz. In *E. denticulus*, the “unique” call type is about 30–40 kHz higher, and contrary to the *Kerivoula* species, we found no strong harmonics. Additionally, we found the “unique” call type less intense than the “common” echolocation call which is again opposite to the findings in K. pellucida and conflicts with a potential long-range communication function. The fact that this “unique” call type always appeared right before the typical echolocation call suggests that it is strongly connected to the physiological mechanism of the “common” echolocation call formation and it might only be a malfunction of

Table I. Basic biometric data of the studied specimens. “arm length” means forearm length here.

HNHM No.	sex	arm length (mm)	weight (g)
23030	female	34.3	4.5
23052	male	34.2	5.0
23057	female	35.7	5.0

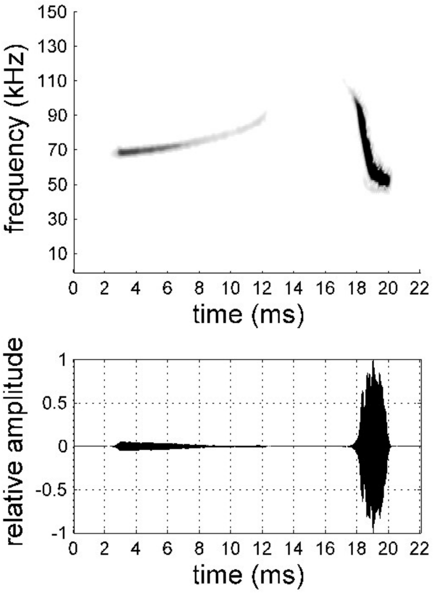

Figure 2. Spectrogram (above) and oscillogram (below) of the “unique” call type with increasing frequency (on the left) and the “common” echolocation call with decreasing frequency modulation (on the right) in *E. denticulus*.

Table II. Descriptive statistics of the echolocation call parameters in *E. denticulus*. In each parameter, we provided the mean value with the standard deviation (mean (SD)), the minimum and maximum values (min-max) and the lower and upper quartiles (LQ-UQ) in separate lines. The last column contains the secondary means and minimum and maximum values of each parameter based on the mean values of the three individuals.

Parameter	Measure	HNHM 23030 (N=174)	HNHM 23052 (N=37)	HNHM 23057 (N=32)	all individuals (N=3)
F_{start} (kHz)	mean (SD)	112.9 (4.1)	107.2 (5.7)	106.5 (4.2)	108.9
	min-max	76.2–119.5	79.2–112.0	89.7–113.0	106.5–112.9
	LQ-UQ	111.9–114.5	107.0–109.5	104.8–108.5	
F_{end} (kHz)	mean (SD)	51.1 (2.4)	53.9 (1.9)	51.1 (2.5)	52.0
	min-max	44.0–57.4	49.9–58.4	46.9–58.4	51.1–53.9
	LQ-UQ	49.7–52.9	53.4–55.4	49.2–52.9	
F_{BW} (kHz)	mean (SD)	61.9 (5.0)	53.4 (5.8)	55.5 (5.7)	56.9
	min-max	23.8–71.5	26.8–59.1	31.3–63.1	53.4–61.9
	LQ-UQ	59.8–64.6	53.1–55.6	53.9–58.9	
F_{maxE} (kHz)	mean (SD)	63.0 (7.4)	61.1 (5.6)	60.9 (7.2)	61.7
	min-max	50.8–95.7	55.7–76.7	52.7–78.1	60.9–63.0
	LQ-UQ	58.6–65.9	56.6–63.5	55.7–65.9	
T (ms)	mean (SD)	1.87 (0.38)	2.11 (0.51)	2.10 (0.61)	2.03
	min-max	0.86–2.75	1.04–2.97	0.74–3.25	1.87–2.11
	LQ-UQ	1.58–2.13	1.81–2.49	1.70–2.56	
PI (ms)	mean (SD)	47.6 (28.0)	69.7 (33.4)	90.0 (130.2)	69.1
	min-max	18.6–247.8	32.8–234.0	20.1–541.1	47.6–90.0
	LQ-UQ	33.5–53.7	54.6–82.1	31.9–64.0	

this process due to stress or exhaustion. It is doubtless that further examinations are required to discover the function of this type of call.

Some bat species that use wide broadband frequency modulated echolocation signals like *Kerivoula* and *Murina* spp., can produce a specially hooked call start, where the starting frequency is lower than the maximum frequency [18]. In *E. denticulus*, this hook is not that well-expressed. However, at start of the call, the narrowband FM part seems typical in this species. The function of this short component has not been discussed in the literature yet, but it may be related to the call formation mechanism.

It is worth noting that *Tylonycteris* and *Glischropus* spp., occuring in the same biogeographic region, have echolocation calls with a structure similar to that of *E. denticulus* [19]. Based on morphological and phylogenetic analyses [20], *Glischropus* is close to the genus *Pipistrellus*, *Tylonycteris* is related to the genus *Vespertilio*, and *Eudiscopus* is close to the genus *Myotis*. The FM-CF echolocation call type is also known from the Neotropical bat *Myotis nigricans* [21] and the Old World bat *Myotis siligorensis* [22]. The call structure of *Eudiscopus denticulus* could be another appropriate example of convergent evolution, as the similarity of the calls suggests ecological adaptation rather than phylogeny [23, 24].

It is important to note that the echolocation call parameters provided hereby (Table II) should be used with some caution during acoustic species identification. First of all, these recordings were taken only from three specimens from one spot in Vietnam, which means that these results cannot predict the whole variation of the *E. denticulus* calls for a larger geographical area (e.g. [25]). Second, some parameters, like pulse length and pulse interval might be larger than the ones provided in the statistical table (Table II) in case of a more open habitat [16]. Finally, call shape can vary according to the flight and to the recording situation [14].

We firmly believe that the published call parameters and the predicted foraging habitat will help to find this species in the wild more frequently than before, and our results encourage additional studies in a fast changing region where it is critical to obtain more information on the distribution and ecology of bats [26].

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