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# Vocal repertoire of Asiatic Black Bear (Ursus thibetanus) cubs

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# Vocal repertoire of Asiatic Black Bear (*Ursus thibetanus*) cubs

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The vocal repertoire of the Asiatic Black Bear (*Ursus thibetanus*) has been poorly studied and until recently only two call types (chuffing and humming) have been described. Here I investigate the vocalizations of three wild orphaned cubs (two males and one female) reared by two observers in natural conditions in the Russian Far East. I grouped the calls into structural types, and then compared them with existing literature data on vocalizations of the same, as well as other species of the Ursidae family. In total, 1302 calls were classified visually from spectrograms into seven call types: *whine*, *moan*, *yelp*, *grunt*, *snort*, *chuffing* and *humming*. Classification results were verified with discriminant function analysis and randomization. I also fixed the presence of nonlinear phenomena (NLP) and articulation effects in calls. *Whine* was the most frequently recorded, as well as the most structurally variable call type due to a high rate of NLP. These results indicate that the vocal repertoire of the Asiatic Black Bear cubs is graded, but includes at least two discrete sound types. This work needs to be continued with further studies of vocalizations of cubs and adults of this species to verify the results of this preliminary study.

**Keywords:** Asiatic Black Bear; *Ursus thibetanus*; vocal repertoire; nonlinear phenomena; articulation effect



## Introduction

The vocal repertoire of only one species of the family Ursidae, the Giant Panda (*Ailuropoda melanoleuca*), has been studied comprehensively in captivity (Peters 1982, 1985; Kleiman and Peters 1990; Charlton et al. 2009a, 2009b, 2010, 2011; Stoeger et al. 2012); Giant Panda vocalizations differ greatly from that of the other species of Ursidae (Peters 1982). Among other bear species, the vocal repertoire of a mother Spectacled Bear (*Tremarctos ornatus*) and her cub was investigated at Lincoln Park Zoo (Moss 1987; Elowson 1989). For the American Black Bear (*Ursus americanus*), Sloth Bear (*Melursus ursinus*), Brown Bear (*Ursus arctos*) and Sun Bear (*Helarctos malayanus*), only verbal and onomatopoetic call descriptions exist (Jordan 1974; Laurie and Seidensticker 1977; Pazhetnov 1990; Pasitschniak-Arts 1993; Kilham and Gray 2002; Hall and Swaisgood 2009). In addition to these studies, the structures of two call types in various species of Ursidae, chuffing (Wemmer et al. 1976; Peters 1978, 2006) and humming (Peters et al. 2007; Derocher et al. 2010), were analysed.

In Russia, the Asiatic Black Bear (*Ursus thibetanus ussuricus*) inhabits only the deciduous and mixed forests of the southern Far East (Bromley 1965). In these forested habitats, sounds undergo structural distortions such as amplitude fluctuations and reverberations, which are deleterious to communication (Richards and Wiley 1980).

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However, sounds in forests play a considerable role in communication due to frequent obstruction of visual contact between individuals (Nikolski 1984). Rigorous studies of Asiatic Black Bear vocalizations have never been done whether in captivity, or in the wild. Some observations on the vocal behaviour of this species were conducted in Glasgow Zoo (O'Grady et al. 1990) and in the wild (Kolchin 2011), but no audio records were analysed. According to Bromley (1965), Asiatic Black Bears rarely produce any calls except for the roaring of mating males and the "purring" of cubs.

In this study, I focused on the vocal repertoire of Asiatic Black Bear cubs. I classified the vocal repertoire of three orphaned cubs according to the structure of the calls, including analysis of nonlinear phenomena (NLP) and articulation effects. NLP (deterministic chaos, subharmonics, sidebands and frequency jumps) come from irregular oscillation of paired vocal folds (Wilden et al. 1998; Volodin et al. 2005), and articulation effects are made via articulators (soft palate, mandible, tongue and lips), not connected with vocal folds (Fant 1960; Riede et al. 2000; Gogoleva et al. 2008). Both NLP and articulation effects were found in the calls of various mammalian species which greatly enhance the variability of call structure (Tokuda et al. 2002; Gogoleva et al. 2008; Stoeger et al. 2011).

Acoustical studies made on wild but habituated orphaned bear cubs, reared in their natural environment, have advantages over those conducted in zoological parks, because of the opportunity to record calls from a distance of 1–2 m while the cubs are engaged in a great variety of behavioural contexts. Our study had two objectives: (1) to describe the vocal repertoire of the Asiatic Black Bear cubs and (2) to compare and to match call types with existing literature data on vocalizations of various species of the family Ursidae in order to eliminate confusion in vocal terminology.

## Materials and methods

### *Subjects and study site*

The work was conducted in 2009–2010 within the Durminskoe game preserve (48°04′N, 135°50′E), which is situated in the boreal coniferous forest zone on the western slopes of the Sikhote-Alin Mountains in the Khabarovskiy region of Russia. Our study was carried out within the Asiatic Black Bear orphaned cubs rehabilitation pilot project (Pizyuk and Sagatelova 2009) according to Dr V.S. Pazhetnov's methods for rearing orphaned Brown Bear cubs (Pazhetnov et al. 1999). In March 2009, three wild bear cubs (two males and one female) orphaned after den hunts were taken for rehabilitation. The three cubs, then aged 2.5–3.5 months, were kept inside a wooden box in a "den-house" – a heated wooden barn within the game preserve. In mid-April, the cubs were moved to an outdoor enclosure (1.5 m × 2 m × 3 m) in a remote forested area, where they stayed only during the night. Immediately upon emerging from the den-house in April 2009, the cubs (aged 3.5 months) demonstrated a strong following reaction (Lorenz 1937; Slonim 1976; Pazhetnov 1990) to two observers (including the author). The following reaction persisted until the cubs' release; however, it lessened as the cubs aged. During all experimental work, the observers never spoke while in the presence of the cubs, and tactile contact between the observers and the cubs was limited to handling during bottle feeding, weighing and necessary medical procedures. The observers used a non-vocal sound, produced by clapping hands, to communicate with a cub that was lost and to help him locate the position of the rest of the group. No other humans were in contact with the cubs. The orphaned cubs grew habituated to the two observers, but were unhabituated to other people and demonstrated inborn defensive reactions towards humans and signs of their presence (my unpublished data).

Every day (except for days with extremely inclement weather) between April 2009 and late October 2009, the surrogate family (three cubs and one to two observers) made excursions into the forest, lasting 6–8 h, via selected routes. Routes were planned by the observers according to seasonal dispersal of main forage resources. During these excursions, cubs foraged on natural foods and investigated the territory; observers did not control or influence their behaviour, except for route planning and protection from predators (wild Asiatic Black and Brown Bears and Amur tiger). After each day's excursion, the cubs received supplementary feeding: infant milk formula (at the age 2.5–3 months), which was later replaced by a mix of oat flakes, porridge, buckwheat, millet and wheat with added minerals and vitamins. Although their social environment differs from truly wild cubs, orphaned cubs reared according to the methods of V.S. Pazhetnov develop normal feeding and defensive skills, and by 6 months of age they are ready for independent living in the wild (Pazhetnov et al. 1999).

For readability purposes, I assigned names to the cubs. The first male cub I called "Yasha". He came from the Primorskiy region. The two twins were named "Shum" (male) and "Shiksha" (female), and came from the Khabarovskiy region of the Russian Far East. I recorded calls regularly during daily excursions with the cubs into the forest from March until October 2009 (1200 h of visual observations) and from April until August 2010 (800 h). From early November 2009 until mid-April 2010, the cubs hibernated in an artificial den. After their emergence from the artificial den, excursions into the forest were continued. In late August 2010, the cubs (aged 20 months) were fitted with plastic ear-tags and released into the wild in the vicinity of the study area.



### *Acoustic data collection and analysis*

Vocalizations of the three cubs were recorded in the den-house in March 2009 (cubs' age 3.5 months) and in the forest for the remainder of the experiment (cubs' age 4–9 and 17–20 months). Records were made via a Zoom H2 Handy Recorder with integral microphone (sampling frequency 96 kHz, resolution 24 bits). For every call sequence, I registered the date and time, the name of the vocalizing cub, the behavioural context, distance between the cub and the microphone (with accuracy to 0.5 m) and location. The distance between the call source and the recorder was between 0.5 and 20 m, and averaged 2–3 m. I obtained 220 recordings of various lengths, and the total recording time of the pieces chosen for analysis was 254 min (mean duration 1.2 min).

Acoustical material was processed via Praat v. 5.3.34 DSP Package (P. Boersma and D. Weenink, University of Amsterdam, the Netherlands) and Avisoft SASLab Pro v. 4.33 (Avisoft Bioacoustics, Berlin, Germany). Call types were identified visually from spectrograms in Praat. For call structure analysis, I chose 1302 high-quality calls, free from background noise and overlapping calls. Samples of calls were chosen equally among the cubs, taking into consideration the cubs' age, identity and behavioural context (my unpublished data). Of the 1302 calls analysed, 278 calls belonged to Yasha, 567 belonged to Shum, 246 belonged to Shiksha and for 211 calls (mostly snort, chuffing and humming), the caller was not identified. For some rarely emitted calls (moan and grunt), I analyzed all recorded calls.

Frequency and time-domain measurements of calls were made using Praat (Fast Fourier Transform (FFT) method, view range = 150–7000 Hz, window length = 0.01 s, time steps = 1000, frequency steps = 250, hamming window shape, dynamic range = 50 dB). Source-related vocal parameters were measured by extracting the fundamental frequency (F0) contour of each call using an autocorrelation method ((Sound: To Pitch (cc) command), time step = 0.01 s, pitch range = 200–2000 Hz). The values of mean (*F0 mean*), minimum (*F0 min*) and maximum (*F0 max*) F0 across the call were included in our analyses. To characterize the F0 variation along the call, we measured the F0 modulation *range* (*F0 max* minus *F0 min*). We also included the total duration of each call (*dur*), the mean harmonics-to-noise ratio (*HNR*) (Mean harmonics-to-noise ratio command) and a measure of F0 variation: *jitter* (stability of the pitch period) (Titze et al. 1987), which is the mean absolute difference between frequencies of consecutive F0 periods divided by the mean frequency of F0 (Jitter (local) command).

I used the following parameters of spectrograms in Avisoft SASLab Pro: Hamming window, 1024 points FFT, 100% frame size and 96.87% overlap. Here, we automatically measured five energy parameters within the energy spectrum window: peak frequency (*F peak* – maximum amplitude frequency (kHz)), lower, central and higher quartiles of the energy spectrum (*q25*, *q50* and *q75* – 25%, 50% and 75% of the call energy) and frequency bandwidth (*bw* – spectrum width at −10 dB). For the majority of calls, the sampling rate was 16 kHz (bandwidth 20 Hz, frequency resolution 16 Hz and time resolution 2 ms) and for low-frequency calls, the sampling rate was converted to 11.025 kHz (bandwidth 14 Hz, frequency resolution 11 Hz and time resolution 2.9 ms). The measurements were exported automatically from Avisoft to Excel (Microsoft Corp., Redmond, WA, USA). Spectrograms of calls were saved from Avisoft.

In all voiced calls, I registered presence, type and duration of NLP visually on spectrograms in Avisoft. Calls were defined as being harmonic (with no evidence of NLP) or nonlinear (having both nonlinear and harmonic segments, or being wholly nonlinear) (following Riede et al. 2007; Stoeger et al. 2011). The relative duration of NLP (%) was calculated by dividing the total duration of NLP by the call duration (in the manner of Stoeger et al. 2011; Stoeger et al. 2012). I registered presence of NLP if it comprised at least 5% of the duration of the call. In whines, I also fixed the form of frequency modulation of the fundamental frequency contour (arcuate or undulate) and presence of articulation effect flutter. The flutter was a repeatedly produced inverted-U modulation of the fundamental frequency contour (Gogoleva et al. 2008). In calls with the undulate form of frequency modulation of F0 contour, I measured the period of modulation as a mean distance (in ms) between the consecutive peaks of F0. For periodical calls, such as chuffing and humming, I also measured the duration of the call series, duration of inter-call and inter-series intervals and the repetition rate (number of calls per second in a series).

I tried to find synonymic terms or similar call types in literature data on vocal repertoires of various species of Ursidae (excluding Giant Panda) and the call types I found in the repertoire of the Asiatic Black Bear cubs. Comparison between call types, found by us and by other authors, was based on the descriptions of the call sound and its behavioural context (my unpublished data). For the most part, vocalizations described within literature sources were classified by aural perception, the vocalizing cub's behaviour and emotional state, but not by call structure. Only a few authors (Wemmer et al. 1976; Peters 1978; Moss 1987; Elowson 1989; Peters 2006; Peters et al. 2007; Derocher et al. 2010) provided spectrograms and structural parameters of bear vocalizations, so I was able to compare call types by structure.

### *Statistical analysis*

Statistical analysis was carried out using Statistica v. 7.0 (StatSoft, Inc., Tulsa, OK, USA). All mean values are given as mean ± standard deviation (mean ± SD). I used discriminant function analysis (DFA) to test the validity of call type categories previously constructed by

Table 1. Structural parameters (mean ± SD (range)) of seven call types (notations as "Materials and methods" section).

| | Whine ($N = 740$) | Moan ($N = 56$) | Yelp ($N = 110$) | Grunt ($N = 16$) | Snort ($N = 83$) | Chuffing ($N = 141$)[a] | Humming ($N = 181$) |
|---|---|---|---|---|---|---|---|
| Dur (s) | 1.13 ± 0.52 (0.27–5.24) | 1.59 ± 1.27 (0.11–5.85) | 0.31 ± 0.11 (0.14–0.78) | 0.18 ± 0.04 (0.12–0.27) | 0.14 ± 0.03 (0.08–0.22) | 0.04 ± 0.01 (0.02–0.06) | 0.05 ± 0.01 (0.02–0.08) |
| F0 min (kHz) | 0.66 ± 0.22 (0.20–1.80) | 0.32 ± 0.08 (0.20–0.50) | 0.65 ± 0.25 (0.20–1.15) | 0.59 ± 0.29 (0.23–1.09) | – | 0.27 ± 0.06 (0.20–0.55) | 0.26 ± 0.71 (0.20–0.45) |
| F0 mean (kHz) | 0.76 ± 0.25 (0.24–1.85) | 0.41 ± 0.08 (0.27–0.58) | 0.95 ± 0.24 (0.50–1.63) | 0.68 ± 0.31 (0.28–1.20) | – | 0.31 ± 0.07 (0.22–0.64) | 0.28 ± 0.89 (0.21–0.49) |
| F0 max (kHz) | 0.85 ± 0.31 (0.24–1.89) | 0.48 ± 0.09 (0.36–0.72) | 1.13 ± 0.28 (0.66–1.90) | 0.79 ± 0.35 (0.32–1.48) | – | 0.35 ± 0.08 (0.23–0.73) | 0.31 ± 1.02 (0.22–0.59) |
| Range (kHz) | 0.19 ± 0.17 (0.02–0.95) | 0.16 ± 0.07 (0.04–0.37) | 0.48 ± 0.23 (0.12–1.34) | 0.20 ± 0.11 (0.04–0.46) | – | 0.08 ± 0.05 (0.09–0.20) | 0.02 ± 0.02 (0.00–0.10) |
| HNR (db) | 9.47 ± 6.42 (0.17–32.47) | 12.59 ± 3.97 (4.30–20.89) | 10.83 ± 5.00 (2.15–24.48) | 4.10 ± 1.64 (1.48–6.21) | – | 6.22 ± 1.89 (1.78–12.72) | 7.63 ± 3.24 (2.60–15.94) |
| Jitter (%) | 3.45 ± 2.67 (0.16–11.39) | 2.81 ± 1.21 (1.13–6.48) | 3.32 ± 1.63 (0.70–7.60) | 8.57 ± 1.86 (6.01–12.59) | – | 6.09 ± 2.40 (3.03–12.27) | 4.14 ± 2.74 (0.78–14.47) |
| F peak (kHz) | 0.92 ± 0.55 (0.21–4.09) | 0.41 ± 0.08 (0.25–0.60) | 1.22 ± 0.59 (0.34–3.68) | 0.73 ± 0.38 (0.25–1.42) | 0.86 ± 0.32 (0.21–1.76) | 0.30 ± 0.08 (0.21–0.60) | 0.31 ± 0.12 (0.12–0.64) |
| q25 (kHz) | 0.85 ± 0.39 (0.25–3.48) | 0.34 ± 0.11 (0.08–0.51) | 1.05 ± 0.35 (0.38–2.06) | 0.69 ± 0.25 (0.30–1.16) | 1.87 ± 0.63 (0.12–3.27) | 0.40 ± 0.15 (0.24–1.03) | 0.28 ± 0.12 (0.08–0.51) |
| q50 (kHz) | 1.49 ± 0.86 (0.34–8.01) | 0.65 ± 0.56 (0.30–3.05) | 1.65 ± 0.62 (0.64–3.66) | 1.15 ± 0.41 (0.51–1.89) | 4.01 ± 0.79 (2.28–5.38) | 1.23 ± 0.79 (0.34–4.04) | 0.45 ± 0.27 (0.21–0.55) |
| q75 (kHz) | 2.87 ± 1.40 (0.75–14.08) | 1.61 ± 1.64 (0.43–8.05) | 2.92 ± 0.92 (0.90–5.34) | 2.65 ± 1.57 (0.94–6.33) | 6.63 ± 0.99 (4.60–8.91) | 3.75 ± 1.74 (1.20–8.69) | 1.06 ± 0.97 (0.30–8.05) |
| bw (kHz) | 0.26 ± 0.22 (0.03–1.55) | 0.13 ± 0.05 (0.06–0.30) | 0.36 ± 0.32 (0.04–1.85) | 0.31 ± 0.18 (0.10–0.68) | 0.16 ± 0.10 (0.04–0.68) | 0.18 ± 0.12 (0.04–0.94) | 0.16 ± 0.06 (0.08–0.34) |

[a] Values presented only for the voiced (middle) component of a complex call.

visual inspection of spectrograms and aurally. I examined 12 structural parameters (*dur*, *F0 mean*, *F0 min*, *F0 max*, *range*, *jitter*, *HNR*, *F peak*, *q25*, *q50*, *q75* and *bw*) for six voiced call types (whine ($N = 680$), moan ($N = 63$), yelp ($N = 81$), grunt ($N = 14$), chuffing ($N = 36$) and humming ($N = 72$), $N$ – number of analysed calls of each putative call type). Cases ($N = 946$) were represented by parameters measures from a single call. I also conducted DFA separately for Yasha ($N = 228$), Shum ($N = 492$) and Shiksha ($N = 226$). As the values of several acoustic parameters of moan, yelp and grunt did not satisfy the criteria of normality with the Kolmogorov–Smirnov test; I calculated the decimal logarithm of all data values to introduce them into the DFA. I used randomization tests for misclassification probability (Solow 1990) to calculate the probability of random classification of calls to the predicted types. This procedure implicates a random dividing of the input data-set into a number of groups, equal to the number of classification groups used in the DFA. Then, the DFA is carried out to test the validity of the classification of these random groups. Obtained probability of correct classification to random groups is considered to be the probability of random classification for the original data-set. I carried out 10 randomization procedures and calculated the mean value of random classification probability.



## Results

### *Description of the vocal repertoire*

I classified the vocalizations of the cubs into seven discrete call types: six voiced (whine, moan, yelp, grunt, chuffing and humming) and one unvoiced (snort). Structural parameters of these call types are shown in Table 1. Transient variants of these calls were found between whine and the other five voiced call types. The duration of the calls within the vocal repertoire of the Asiatic Black Bear cubs can be divided into long (whine and moan), short (yelp, grunt and snort) and very short periodical (chuffing and humming) call types. Concerning peak frequency, there are high-pitched (yelp), medium-pitched (whine, snort and grunt) and low-pitched (moan, chuffing and humming) call types (Figure 1). The majority of calls are produced by quasi-periodic vibrations of the vocal folds, i.e. via phonation. In only one sound type (snort) is the tonal component missing, so the vocal

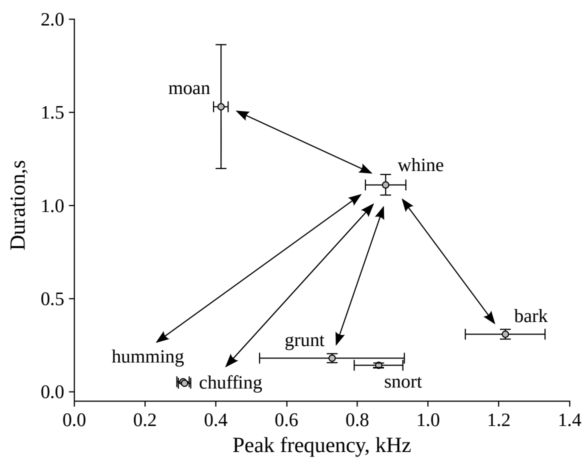


Figure 1. Diagram of call types distribution versus duration and peak frequency (mean ± 95% CI) and transitions (arrows) between call types ($N$ as in Table 1).

folds are not involved in its production. I found no call types homologous to the purring of Felids (Peters 2002).

### *Whine*

*Whine* is the most frequently recorded call type: 162 (73.5%) of 220 records contained whines. All three cubs regularly emitted whines during the study period (age 3–20 months). *Whine* is a long tonal call, usually with an arcuate form of frequency modulation (98.2% of calls) (Figure 2a) or, rarely, with undulate form of frequency modulation (1.8%) with variable periods of modulation (146 ± 78 ms, $N = 8$) (Figure 2c). The peak harmonic is usually F0, but in some cases it can be F1 or F2. Two-thirds (65%) of whines are nonlinear, i.e. contain different NLP and/or articulation effect flutter.

### *Moan*

*Moan* is a low-frequency, slightly modulated narrowband harmonic call, uttered usually with the mouth closed. The fundamental frequency always conveys the maximum energy of the call. *Moan* never contains NLP or flutter (Figure 2b).

### *Yelp*

*Yelp* is structurally opposite to *moan*. It is a short tonal call with arcuate form of frequency modulation, large frequency modulation range and high peak and maximum fundamental frequencies. Two-thirds (66%) of yelps are nonlinear, but they never contain flutter. Variable location and duration of NLP fragment in calls lead to different sounding yelps. The verbalization of a yelp, produced with an open mouth, sounds like "au!", "jau!" or "iu! ". With a closed mouth, the verbalization of a yelp sounds like "um" (Figure 2d).

### *Grunt*

*Grunt* is a short tonal call with a duration similar to a yelp, but mean, min and max F0, range and HNR values of *grunt* are lower than those of *yelp*. *Grunt* differs from *whine* in lower HNR and a shorter call duration. Grunts are always nonlinear but never contain flutter. Transient calls could have a grunt-like fragment in the beginning of a harmonic whine (Figure 2e).

### *Snort*

*Snort* is a short, explosive unvoiced sound, produced by a rapid turbulent exhalation of air through the nose with mouth closed. The spectrogram of snort looks like a "cloud" of wideband noise. The duration of a snort is similar to a yelp and a grunt. Unlike the other call types, the snort appeared in the vocal repertoire of the cubs at the age of 6 months (Figure 2f).

### *Chuffing*

*Chuffing* represents a repetitive three-component call (Figure 2 g) with a regular temporal succession of three components; chuffing calls are usually made in a series. The first component of these complex calls is a short, high-pitched tonal unvoiced click

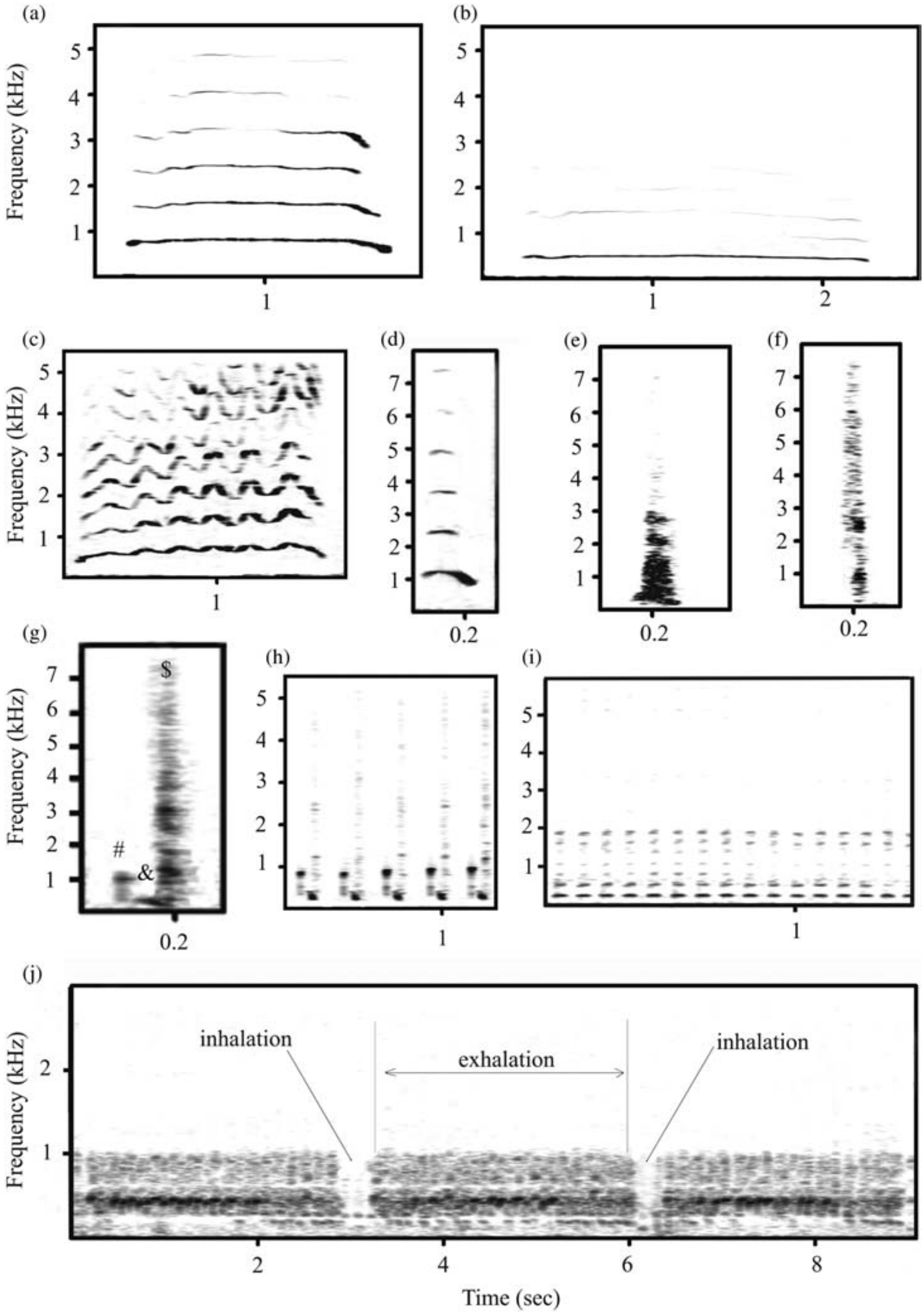


Figure 2. Spectrograms of seven call types of Asiatic Black Bear cubs: (a) whine with normal phonation, (b) moan, (c) whine with undulate frequency modulation (modulation period 0.23 s), (d) yelp, (e) grunt, (f) snort, (g) one three-component complex call of chuffing (# – tonal click, & – tonal call, $ – noisy pulse), (h) chuffing series (five single calls with tonal click before and noisy pulse after each call), (i) humming series (13 single calls) and (j) three series of humming, produced during exhalation and divided by inhalation intervals.

(*dur* = 0.03 ± 0.01 s, *F0 max* = 0.98 ± 0.10 kHz, *N* = 115). The second component consists of a low-pitched tonal voiced call (*dur* = 0.06 ± 0.02 s, *F0 max* = 0.35 ± 0.08 kHz, *N* = 115, *N* – number of calls). This is followed by a third component – a noisy pulse (*dur* = 0.05 ± 0.01 s, *F peak* = 1.30 ± 0.13 kHz, *N* = 52). Figure 2 h shows a sequence of five complex calls in the chuffing series. Each individual call within the series contains a tonal click, a tonal call and a noisy pulse. Continuous series of chuffing may last up to 20 s and contain 2–60 or more three-component calls, each emitted with different intensities. The duration of the interval between complex calls is 0.13 ± 0.05 s, and the repetition rate is 3.6 ± 0.5 calls per second (*N* = 22). There are transient calls between chuffing and whine: the same three-component call containing a voiced component longer than the usual chuffing call (duration about 0.1 s, *N* = 6), uttered in shorter series (2–5 calls running) in a sequence of whines.

*Humming*

*Humming* is a series of very short, low-frequency tonal calls, repeated at regular intervals (Figure 2i). Series of humming are produced during exhalation and are separated by equal intervals, during which the animal inhales (Figure 2j). The duration of a humming series is 5.75 ± 5.59 s (min = 1.46, max = 19.78, *N* = 36), the duration of inter-series intervals is 0.38 ± 0.11 (*N* = 36), the duration of an inter-call interval is 0.03 ± 0.01 (*N* = 21) and the calling rate is 11.79 ± 1.39 (min = 9.93, max = 14.21, *N* = 21) calls per second in a series. Frequency modulation range of humming is negligible; *F0* and *F peak* values of calls are almost invariable throughout a series. Transient calls between humming and whine represent a whine, constructed of conjugated calls of humming, with an undulate form of frequency modulation. The duration of these calls is equal to the duration of a humming series (for a 3–4 months old cub *dur* = 2.04 ± 0.34 s, *N* = 13) and they repeat at regular intervals, equal to those between humming series (0.30 ± 0.07 s, *N* = 13), but maximum fundamental frequency is closer to that of a whine (*F0 max* = 0.85 ± 0.06 kHz, *N* = 13).

***Quantitative assessment of the call types***

Discriminant analysis revealed significant differences between six voiced call types (whine, moan, yelp, grunt, chuffing and humming) in the 12 parameters: call duration, mean, minimum and maximum fundamental frequencies, range, jitter, HNR, peak frequency, lower, central and upper quartiles, bandwidth. The most significant parameter for discrimination was duration of calls (Table 2).

We interpret loadings in the structure matrix if they are 0.30 or higher. Based on the structure matrix (Table 3), the predictor variables strongly associated with discriminant function 1 are call *duration* (*r* = 0.770) and *F0 mean* (*r* = 0.310). The following variables are strongly associated with discriminant function 2: call *duration* (*r* = −0.413), *F0 mean* (*r* = 0.578), *F0 min* (*r* = 0.326), *F0 max* (*r* = 0.566), *range* (*r* = 0.536), *f peak* (*r* = 0.599), *q25* (*r* = 0.634), *q50* (*r* = 0.543) and *q75* (*r* = 0.573).

Table 4 shows the per cent of correct classification of calls into predicted types. Mean percentage of the correct classification for the three cubs is 95.44%, for Yasha − 99.65%, for Shum − 94.51% and for Shiksha − 100.00%. These values are significantly higher than the value of random classification which, for the six call types, is 23.37 ± 3.59% (*N* = 10). The minimum percentage for correct classification was noted for *moan* (78.33%), whereas the maximum was noted for *grunt* and *chuffing* (100.00%). Figure 3 is a scatter plot, which graphically represents the results of the discriminant analysis totally for

Table 2. Results of discriminant function analysis of six call types by 12 parameters (Wilks' λ: ~0.0229; $F_{60,4335} = 89.683$; $p < 0.001$).

| Parameters | Wilks' λ | $F_{5,925}$ | *p* |
|---|---|---|---|
| Duration | 0.1226 | 807.5 | <0.001 |
| Mean fundamental frequency | 0.0269 | 33.2 | <0.001 |
| Minimum fundamental frequency | 0.0268 | 31.9 | <0.001 |
| Maximum fundamental frequency | 0.0256 | 21.9 | <0.001 |
| Range | 0.0256 | 22.0 | <0.001 |
| Jitter | 0.0243 | 11.4 | <0.001 |
| Harmonic-to-noise ratio | 0.0247 | 14.8 | <0.001 |
| Peak frequency | 0.0237 | 7.1 | <0.001 |
| Lower quartile | 0.0246 | 13.9 | <0.001 |
| Central quartile | 0.0233 | 3.7 | <0.01 |
| Upper quartile | 0.0254 | 20.3 | <0.001 |
| Bandwidth | 0.0238 | 7.5 | < 0.001 |

three cubs and separately for each of them. For the general sample, *whines*, *yelps*, *chuffing* and *humming* separate well in these two functions (Figure 3a). Moans and whines are partly intermixed.

### *Nonlinear phenomena and articulation effects in calls*

I found four types of NLP (deterministic chaos, subharmonics, sidebands and frequency jumps) and one articulation effect (flutter) within the nonlinear calls of the three Asiatic Black Bear cubs. NLP were present within three of the six types of voiced calls: whine, yelp and grunt. Moan, chuffing and humming are harmonic throughout the entire call. Within a whine, more than one fragment with either the same or a different type of NLP and/or flutter usually occurred. Whine ($N = 442$) and yelp ($N = 108$) contained chaos (31% of calls for both), sidebands (31% and 29% of calls), subharmonics (25% and 16% of calls) and rarely frequency jumps (4% and 5% of calls) (Figure 4). Grunt ($N = 16$) contained only chaos and sidebands (both in 50% of calls). In whine, the mean relative duration of NLP was 42.30 ± 40.13% (ranging from 0 to 100%, $N = 442$) of the call duration, in yelp 39.38 ± 34.14% (ranging from 0 to 100%, $N = 108$) and in grunt 98.12 ± 3.28% (*min* = 89%, *max* = 100%, $N = 16$). The articulation flutter effect with

Table 3. Structure matrix of the discriminant function analysis for roots 1 and 2.

| Variable | Root 1 | Root 2 |
|---|---|---|
| Duration | 0.770 | −0.413 |
| Mean fundamental frequency | 0.310 | 0.578 |
| Minimum fundamental frequency | 0.249 | 0.326 |
| Maximum fundamental frequency | 0.287 | 0.566 |
| Range | 0.188 | 0.536 |
| Jitter | −0.083 | 0.071 |
| Harmonic-to-noise ratio | 0.037 | 0.021 |
| Peak frequency | 0.263 | 0.559 |
| Lower quartile | 0.250 | 0.634 |
| Central quartile | 0.152 | 0.543 |
| Upper quartile | 0.143 | 0.573 |
| Bandwidth | 0.004 | 0.187 |

Table 4. Classification matrix of the discriminant function analysis (observed call types are given in rows and predicted call types are given in columns).

| Call type | Whine | Moan | Yelp | Grunt | Chuffing | Humming | Percentage of correct classification |
|---|---|---|---|---|---|---|---|
| Whine | 665 | 5 | 9 | 0 | 0 | 0 | 97.94 |
| Moan | 11 | 47 | 0 | 2 | 0 | 0 | 78.33 |
| Yelp | 13 | 0 | 67 | 1 | 0 | 0 | 82.72 |
| Grunt | 0 | 0 | 0 | 14 | 0 | 0 | 100.00 |
| Chuffing | 0 | 0 | 0 | 0 | 36 | 0 | 100.00 |
| Humming | 0 | 0 | 0 | 0 | 2 | 70 | 97.22 |
| Total | 689 | 52 | 76 | 17 | 38 | 70 | 95.44 |



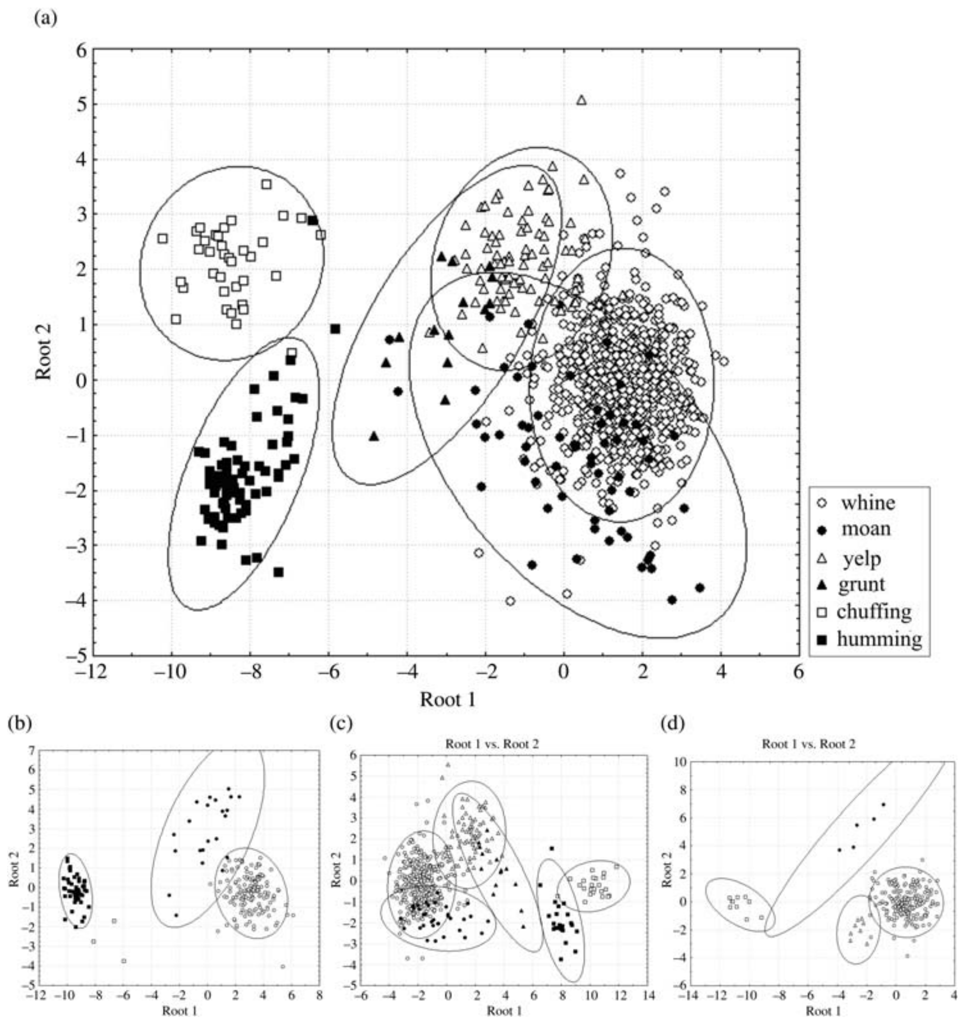


Figure 3. Scatter plot of voiced calls representing the results of function (root) 1 and function (root) 2 of discriminant analysis: (a) general, (b) Yasha, (c) Shum and (d) Shiksha.

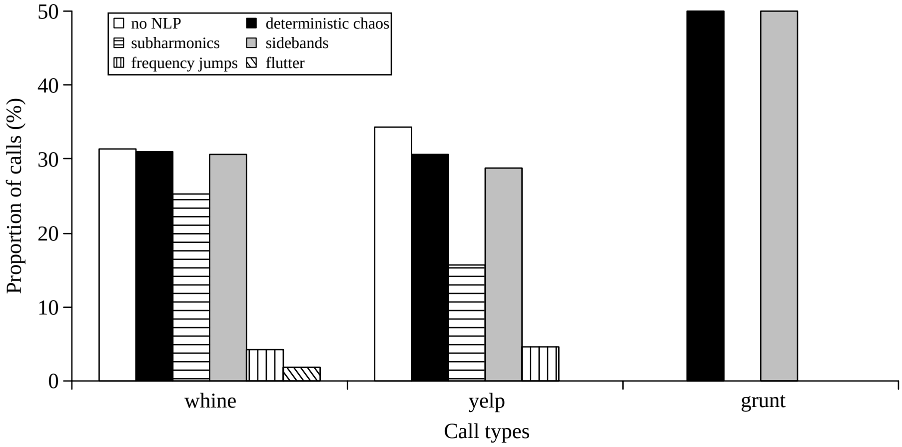


Figure 4. Proportion of calls with NLP and articulatory effect flutter from total number of whines, yelps and grunts.



a modulation period of 23 ± 6 ms ($N = 8$) was noted only in whine in 1.81% of calls. Figure 5 shows examples of calls with various types of NLP and articulation flutter effect.

### *Comparison of call types with literature data*

It was usually possible to compare call types based on onomatopoetic descriptions of the calls' sounds, if those were distinguishable aurally, and by the behavioural context of the calls. Aggressive screams, various types of roars, whines, whimpers, howls, growls and snarls are probably identifiable as whines in our terminology, differing by the duration, the fundamental frequency and by the presence and rate of NLP and flutter within them. The call "num-num num" in vocalizations of American Black Bear cubs (Kilham and Grey 2002), presumably, is equal to whine of the Asiatic Black Bear cubs with an undulate form of frequency modulation (see Fig. 2c), usually uttered by cubs while begging for or defending food. A *yelp* within an Asiatic Black Bear vocalization is the only specific isolation call (my unpublished data), so I judged distress and alarm calls to be synonymous with yelp by functional context or by shortness of the call (yelps). In most sources, *huff* was described as a blowing sound that is quite similar to *snort* in our terminology; huffing was always observed when the animal was anxious. Calls similar to chuffing were found by the onomatopoetic description (e.g. "tut-tut" call) or description of the sound production mode (e.g. jaw-popping), and also by description of the caller's behaviour. Humming-like calls were always tightly connected with a single behavioural context (suckling) and were described as a loud noisy pulsating call. The results of the comparison are shown in Table 5.

## Discussion

This work represents the first profound study of the vocal repertoire of three orphan Asiatic Black Bear cubs living in the wild under custodial care of two observers. Discriminant analysis proved our classification of vocalizations into seven discrete call types, easily distinguishable aurally and visually by spectrograms. We found transient calls between whine and all other voiced call types. Transient (or intermediate) call types are also known

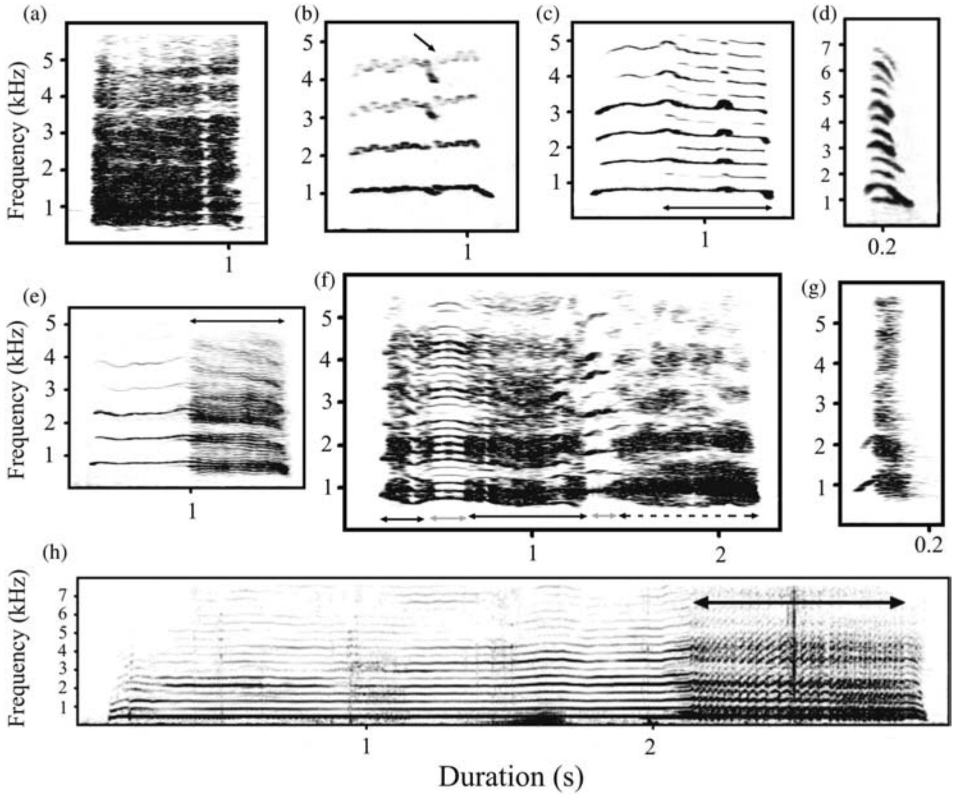


Figure 5. Examples of call spectrograms with NLP and flutter effect: (a) whine with deterministic chaos; (b) whine with undulate frequency modulation (modulation period 0.08 s) and frequency jump (sideling arrow); (c) whine with subharmonics (1/2 of the F0) (horizontal arrow); (d) yelp with subharmonics (1/3 of the F0); (e) whine with sidebands (horizontal arrow); (f) whine with alternation of two fragments with chaos (black arrows), two fragments with subharmonics (grey arrows) and one fragment with sidebands (dashed arrow); (g) yelp with deterministic chaos and (h) whine with articulatory effect flutter (horizontal arrow).



in vocalizations of the Giant Panda (Peters 1982). The vocal repertoire of the Asiatic Black Bear cubs may be regarded as an example of a continuum of structural types of calls (Hauser 1996), where the extreme points are moan, yelp and humming, and whine is situated in between and is connected with all other voiced call types by transient forms. However, snort represents the only sound type produced via turbulence; therefore, it is discrete in relation to the other call types produced via phonation.

*Whine* is the most structurally variable call type. The high polymorphism of whine is connected with high rate and variability of NLP in this call type (Volodin et al. 2005). NLP are widespread among Canidae and Felidae species (Wilden et al. 1998; Riede at al. 2000; Tokuda et al. 2002; Volodin et al. 2005), but have not been previously described for Ursidae except for Giant Panda (Stoeger at al. 2012). In Giant Panda vocalizations (Peters 1982), the structure of bleating is probably similar to that of the whine of the Asiatic Black Bear with undulate frequency modulation, and the moan of a panda is probably similar to a harmonic whine. Articulation effect flutter, a repeated inverted U-modulation of the

Table 5. Synonyms of call types in various species of the Ursidae family.

| Call types (our data) | Synonyms |
|---|---|
| Whine | Scream (4, 5, 6, 7, 8, 10); roar (1, 4, 7, 8, 13); whine (7, 12, 13); growl (5, 12, 13); snarl (8, 13); squeal (4); long squeal (5); bleat (8); yowl (8); howl (4); whimper (5); cry (5); squawk (5); croak (5); bellowing (3); "num-num-num" (8); appalling row (7) |
| Moan | Moan (8, 13); moaning (3); groan (10) |
| Yelp | Yelp (4, 5, 8); alarm call (13); distress call "baaWoOow!" (8); "mew-mew" call (8); short squeal (5); bark (5); "Kurrrr" (10) |
| Grunt | Grunt (7, 13); grunting (3, 6); grunt-whicker (4); woof (8); bark (8); barklike alarm call (8) |
| Snort | Huff (4, 8, 13); huffing (3, 6); blow (10) |
| Chuffing | "tut-tut" call (7); guttural pop (11); guttural cough (13); jaw-popping (3); gulp, gulp-grunt (8); "huh-huh-huh" (8); "ngo-ngo-ngo" (6); rattling, grunt/rattling, grunt/gurgling (4); "tuutucttt" (10) |
| Humming | Purring (1, 11); pulsating call (2); nursing call (8); call of contentment (8); suckling call (6); churring (9); "kerfump" sound (4); low-pitched trill (5), penetrating noise "MMrnnMMrnn" (10); humming (12) |

Notes: References as follows (authors (year) (species)): 1 – Bromley (1965) (*Ursus thibetanus*); 2 – Burghardt and Burghardt (1972) (*U. americanus*); 3 – Jordan (1974) (*U. americanus*); 4 – Laurie and Seidensticker (1977) (*Melursus ursinus*); 5 – Moss (1987) and Elowson (1989) (*Tremarctos ornatus*); 6 – Pazhetnov (1990) (*U. arctos*); 7 – O'Grady et al. (1990) (*U. thibetanus*); 8 – Kilham and Gray (2002) (*U. americanus*); 9 – Russel and Enns (2003) (*U. arctos*); 10 – Castellanos et al. (2005) (*T. ornatus*); 11 – Yudin (2006) (*U. thibetanus*); 12 – Hall and Swaisgood (2009) (*Helarctos malayanus*); 13 – Kolchin (2011) (*U. thibetanus*).



fundamental frequency, was also found in the vocalizations of Domestic Cats (*Felis catus*) (Shipley et al. 1991) and Red Foxes (*Vulpes vulpes*) (Gogoleva et al. 2008).

Chuffing and humming are synapomorphic vocalization types for all members of Ursidae, lacking only in the vocal repertoire of the giant panda (Peters 1982). These call types have been studied in bears much more thoroughly than other call types. Chuffing was firstly described as lip clapping ( = Lippenklappen) (Schneider 1933, cited after Peters 2006), and later was studied in Polar Bears (Wemmer et al. 1976) and other Ursidae species (Peters 1978, 2006). There are also several onomatopoetic epithets, verbally describing the same call type (Table 5). On the basis of the analysis of spectrograms of chuffing of four Ursidae species (Polar, Brown, American Black and Asiatic Black Bears), Peters (2006) concluded that chuffing is an unvoiced call type, because vocal folds do not take part in its production. Chuffing represents a complex type of call production in mammals: this call comprises of at least two structurally different elements – tonal unvoiced click ("plop"-component) and noisy pulse ("huff") (Peters 1978, 2006). Visual observations showed that clicks probably result from repeatedly pulling apart and striking together lips and/or cheeks (Wemmer et al. 1976; Peters 2006) or by snapping the tongue against the roof of the mouth (O'Grady et al. 1990; our data). Noisy pulses are produced by forceful exhalation through opened lips, each with a visible contraction of abdominal musculature (Peters 2006; our data). It is unknown whether a noisy exhalation through the nose contributes to call production (Peters 2006). The mean duration of a click and a noisy pulse in the chuffing of Asiatic black bear females were 0.03 s and 0.05 s respectively (Peters 1978). This corresponds with our data on the chuffing of the cubs. However, according to our material, the cubs' chuffing always contained a short low-pitched harmonic element between a click and a pulse. In three-component calls being transient between whine and chuffing the harmonics are clearly visible in the second component; this indicates the role of vocal folds in production of the second component in a complex call of chuffing.

Humming is a periodical low-frequency vocalization that is not connected to any of the known vocalization types of other terrestrial carnivores; it is not homologous to the purring of Felidae (Peters 2002). Despite the presence of the term humming (Schneider 1933, cited after Peters et al. 2007), authors gave different names to vocalizations of this type (Table 5). All species of Ursidae demonstrate similar structural parameters of humming (Peters et al. 2007). This call type is found within the vocal repertoire of adults, but it is more typical for bear cubs. Our data on structural parameters of humming of the Asiatic Black Bear cubs correspond with that of the 2-month-old Asiatic Black Bear cub, observed by Peters et al. (2007). Duration of inter-series intervals and duration of single calls are almost equal in cubs of all species (Peters et al. 2007). The following parameters of humming were reported for a wild Polar Bear (*Ursus maritimus*) cub, aged 4–5 months ($N = 137$, mean $\pm$ SE): duration of calls $0.05 \pm 0.02$ s, maximum fundamental frequency $0.28 \pm 0.06$ kHz, peak frequency $0.85 \pm 0.15$ kHz, duration of series 0.4–5 s and 30–55 calls in a series (Derocher et al. 2010). These values are close to ours, but peak frequency of humming of the 3–4-month-old Asiatic Black Bear cubs is half as large as in the Polar Bear cub ($0.39 \pm 0.11$ kHz, $N = 90$). Mean breathing rate of a 3–4-month-old bear cub is 30 inhalations per minute, i.e. one normal exhalation lasts about 2 s (Lindstedt and Schaeffer 2002, cited after Peters et al. 2007). Duration of a continuous series of humming often exceeds the duration of normal exhalation (Peters et al 2007; my data); therefore, it is likely that the production of humming requires large energy expenditures (Peters et al. 2007). The maximum duration of a continuous series of trills (16 s) was noted once in vocalization of a spectacled bear cub (Elowson 1989).

Most of the vocalization types (excluding yelp) that I found in the vocal repertoire of the three cubs were noted for adult Asiatic Black Bears in captivity (O'Grady et al. 1990) and in the wild (Kolchin 2011). However, I anticipate that the vocal repertoire of adult bears will be broader including specific calls related to territorial aggression, mating and mother–offspring behaviour, all of which I was unable to study. The data on call structure and vocal behaviour of both adult and juvenile Asiatic Black Bears are definitely lacking.

To conclude, this study provides structural analysis of three Asiatic Black Bear cubs' vocal repertoire. Due to the small sample size, it is necessary to do further studies of the vocal repertoire of both cubs and adult Asiatic Black Bears with a larger sample size to achieve an integral picture of the vocal repertoire of this species. It is also important to estimate the appearance of certain call types in the ontogeny, analysing vocalizations of cubs during the early postnatal period (0–3 months). In the future, it will be interesting to study the vocalizations of other species of Ursidae to discover the ways in which the structure of the vocal repertoire is affected by inter-species diversity in behavioural ecology of bears.

## Supplementary material

Supplementary material for this article is available via the supplementary tab of the article's online page at http://10.1080/09524622.2013.785023.

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