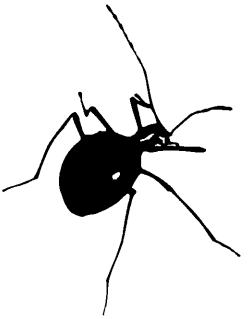

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COMPARISON OF *DUNDUBIA VAGINATA* (AUCHENORRHYNCHA: CICADOIDEA) SONGS FROM BORNEO AND PENINSULAR MALAYSIA

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Abstract We investigated the songs of the cicada *Dundubia vaginata* Fabricius 1787. The sound emission analysis is based on 21 recordings of different individuals from four localities in peninsular Malaysia and 10 recordings from one locality in Borneo. The results were compared to the published description of song pattern from Borneo. The song of *Dundubia vaginata* from peninsular Malaysia is clearly different from Bornean populations' song. Short, narrow banded frequency modulated (FM) first part of bipartite phrases from Borneo resembles the end short part of phrases from peninsular Malaysia. The longer broadband parts of phrases in both populations have similar properties. A song pattern of unknown sympatric cicada species resembling the song of Bornean population has also been recorded at two localities in peninsular Malaysia. The most prominent difference is unequal length of phrases in the song of this unidentified but probably closely related cicada species. *Dundubia vaginata* seems to be not a single taxon but rather a complex of species.

KEY WORDS: *Dundubia vaginata*, Auchenorrhyncha, Cicadoidea, song, acoustics, Borneo, Malaysia

Izvleček – PRIMERJAVA NAPEVOV ŠKRŽADOV VRSTE *DUNDUBIA VAGINATA* (AUCHENORRHYNCHA: CICADOIDEA) Z BORNEA IN POLOTOŠKE MALEZIJE

Raziskali smo napeve škržada *Dundubia vaginata* Fabricius 1787. Analiza napevov je bila narejena na 21 posnetkih različnih osebkov s štirih najdišč v celinski Maleziji in 10 posnetkih z enega najdišča na Borneu. Rezultate smo primerjali z že objavljenim opisom napevov z Bornea. Napevi škržada *D. vaginata* iz celinske Malezije se jasno razlikujejo od napevov bornejske populacije. Kratki, ozkopasovni in frekvenčno modulirani prvi deli dvodelne fraze bornejske populacije so analogni kratkim zadnjim delom fraze populacije iz celinske Malezije. Daljši širokopasovni deli fraz obeh populacij imajo podobne lastnosti. Na dveh najdiščih v celinski Maleziji smo posneli napev nepoznane simpatrične vrste škržadov. Napev je zelo podoben napevu bornejske populacije *D. vaginata*. Največja razlika je v neenaki dolžini fraz tega neidentificiranega, vendar verjetno sorodnega taksona. Naše raziskave kažejo, da je *Dundubia vaginata* v resnici kompleks vrst.

KLJUČNE BESEDE: *Dundubia vaginata*, Auchenorrhyncha, Cicadoidea, napev, akustika, Borneo, Malezija

Introduction

Genus *Dundubia* consists of at least 12 known species and varieties (Overmeer & Duffels, 1967). Songs of several species have already been described (Chou et al., 1997; Boulard, 2001a & 2001b). *Dundubia vaginata* Fabricius 1787 (Auchenorrhyncha: Cicadidae) is one of the most common species of cicada found in tropical rainforests of Malaysia. Its range stretches from China and India over the Malay Peninsula and Philippines to Greater Sunda Islands (Overmeer & Duffels, 1967). In their revision of the genus *Dundubia*, Overmeer & Duffels (1967) found morphological differences in genitalia and opercula of *D. vaginata* males belonging to populations from different islands. These differences were in their opinion not significant enough to warrant further branching of the existing taxon, they did however accept the already established *D. vaginata* var. *nigrimacula* Walker 1850 from Java. A description of the calling song of *D. vaginata* was given by Riede & Kroker (1995) based on the recordings from Borneo.

On several expeditions to peninsular Malaysia members of the Slovenian Museum of Natural History recorded calling songs of cicadas, which according to their morphological characteristics belong to the species *D. vaginata*. These songs differ from those described by Riede and Kroker (1995) and to our knowledge have so far not been reported from Borneo. Members of expedition also recorded *D. vaginata* songs in Borneo. Songs resembling those of *D. vaginata* from Borneo were also heard and recorded in peninsular Malaysia but the animals communicating with these songs have not been observed or collected.

In this paper we:

1. describe songs of *D. vaginata* population from peninsular Malaysia and Borneo,

2. offer a review of Riede and Kroker's description of a calling song of *D. vaginata* from Borneo, since their approach to spectral analysis was different and results therefore do not allow direct comparison,
3. compare these two types of a calling song and the song of an unknown cicada, recorded in peninsular Malaysia resembling the one of *D. vaginata* from Borneo.

Materials and methods

21 songs of the peninsular population were recorded in three different locations in peninsular Malaysia: at Kuala Juram Taman Negara, Merapoh side (1999), Temengor Forest Reserve during the 1st Belum Expedition (1994) and Endau Rompin National Park (1999 and 2002). 10 songs of the Bornean population were recorded in Borneo at Poring Hot Spring, Kinabalu National Park in years 1999 and 2003. 12 songs of an unknown but probably closely related cicada species were recorded in peninsular Malaysia at Endau Rompin National Park (2002) and at Om Sri Joti, Gombak in 1996 (Fig. 1). All songs were recorded at temperatures between 23°C and 29°C. The exact number of animals recorded is almost impossible to determine when recording animals singing in canopy. All we can say is that number of singing animals is equal or lower than the number of recordings.

Recordings were made with a parabolic stereo microphone TELINGA PRO III (d = 54 cm, frequency response from 40 Hz to at least 16 kHz at ± 4dB) and TELINGA PRO V (d = 54 cm). All songs were recorded at 48 kHz sampling rate and 16-bit depth, using various types of SONY DAT recorders. The signals were transferred from DAT to a PowerMac G4 computer via an AUDIOMEDIA III audio card. Measurements were made using Canary 1.2.4 software (Cornell Lab of Ornithology). Oscillograms and spectrograms for publication were made in Raven 1.2 (Cornell Lab of Ornithology).

For the analysis we selected the recordings with the lowest levels of biotic noise. On the first ten measurable phrases of each selected recording of a calling song we

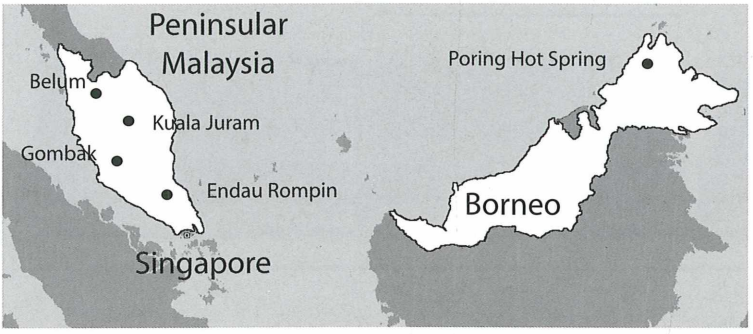

Fig. 1: Map of Malaysia with recording localities.

measured the following parameters: duration of the phrase parts and duration of a pause between phrases. All durations were measured on a spectrogram (FFT frame length: 512 points). In both parts of the phrase we established the locations of frequency peaks on power spectra (FFT frame length: 1024 points). Results were processed statistically with KyPlot 2b15f (by Koichi Yoshioka). Microphones were not calibrated and songs' amplitudes are thus relative. Data are presented as mean ± S.D.

Voucher specimens of cicadas from Borneo and peninsular Malaysia are preserved in the collection of the Slovenian Museum of Natural History (PMSL) in Ljubljana. The recordings from all the localities without the literature citation are stored in the Wildlife Sound Archive of Slovenian Museum of Natural History.

Results

Peninsular Malaysia Population. Peninsular population's calling song consists of sequences of one type of phrase. Each phrase is formed from longer part, designated as A, and shorter part, designated as B (We apply this designation throughout the text: A stands for longer part and B for shorter part). Part A is

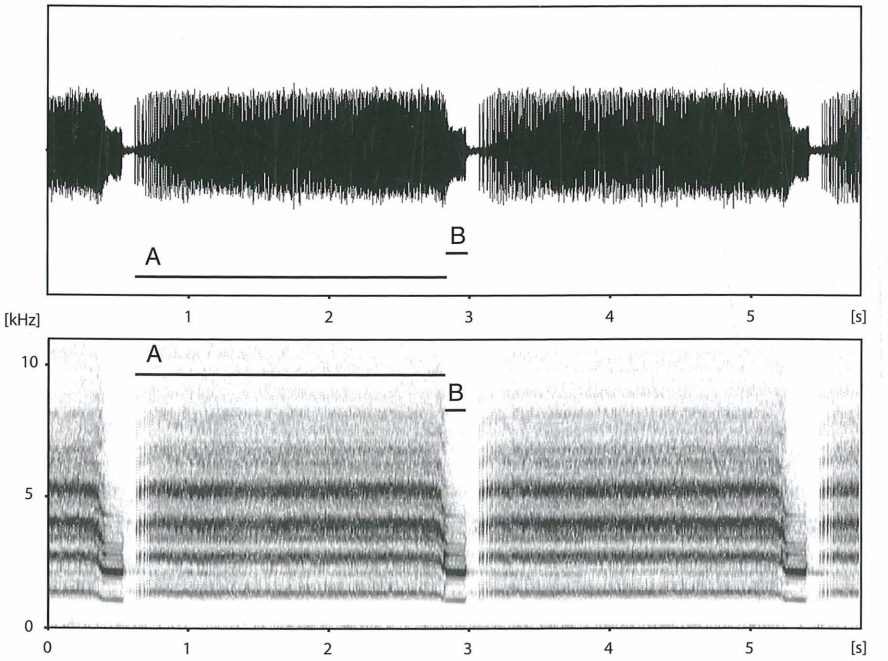

Fig. 2: Oscillogram and spectrogram of *Dundubia vaginata* song from peninsular Malaysia. Since microphones were not calibrated, there is no scale on oscillogram Y-axis.

frequency-constant (CF) and passes into part B via very fast frequency modulation (FM). Part B is also CF but in the transient phase the fundamental frequency drops and the dominant frequency changes (Fig. 2). Part A is 2.3 ± 0.2 s (N = 210) long. Part B is only about 8 % of the length of part A: 0.20 ± 0.03 s (N = 210). Median of pause duration is 0.11 s. Interquartile difference is 0.06 s: the first quartile at 0.09 s and the third at 0.15 s. The fundamental frequency of part A is 1.39 ± 0.03 kHz (N = 210) while the dominant frequency is usually the second or the third harmonic. The first five frequency peaks are always distinguishable while others are often completely masked by biotic noise. Fundamental frequencies' bandwidth of part A is 0.27 ± 0.03 kHz (N = 199) at -10 dB. The fundamental frequency of part B is at 1.08 ± 0.01 kHz (N = 210). The dominant frequency peak is the first harmonic at 2.17 ± 0.07 kHz (N = 210), which is from 6 to 26 dB louder than the fundamental frequency. The third peak is always distinguishable at 3.25 ± 0.11 kHz (N = 210). Other peaks are usually concealed among the sidebands. The major part of sound energy is between 1 and 7.5 kHz. Difference between fundamental frequencies of parts A and B is approximately one and a half tones. Fundamental frequency band of part B is much narrower compared to the width of part A: 0.12 ± 0.01 kHz (N = 186), measured at -10 dB.

Bornean population. Bornean populations' calling song also consists of one type of bipartite phrase (Fig. 4). The phrase starts with shorter part B which is frequency modulated over its entire length of 0.16 ± 0.02 s (N = 100). Fundamental frequency is 0.84 ± 0.01 kHz at the begining of part B and about 50 Hz lower at the end of part B (Fig. 3). Part A of the phrase is CF with duration 1.96 ± 0.31 s and fundamental frequency 0.85 ± 0.02 kHz. Duration of silent intervals between phrases is 0.08 ± 0.02 s Bandwidths of fundamental frequencies are 0.16 ± 0.05 kHz at -10 dB for part B and 0.20 ± 0.06 kHz at -10 dB for part A. At least the first four higher harmonics are observable in all recordings and one of the first three harmonics is the loudest. Other harmonics are also present, but usually hidden due to sidebands or background noise. Differences in measurement values between recordings from

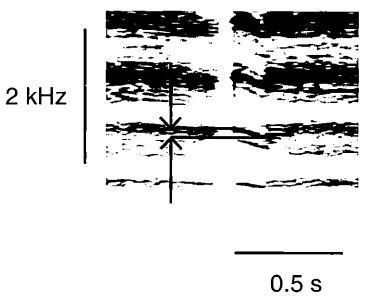

Fig. 3: Frequency modulation in part B of *Dundubia vaginata* song from Borneo.

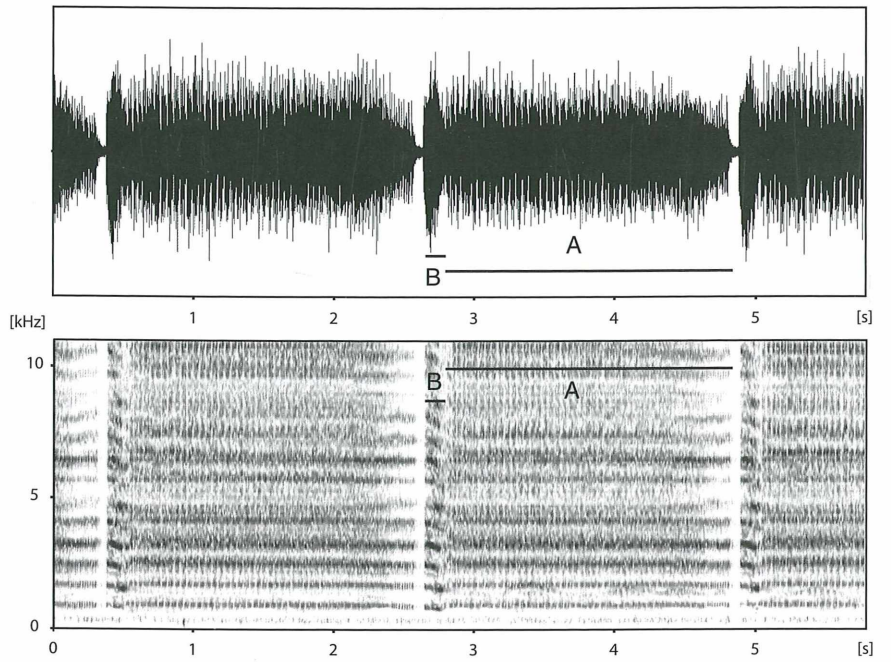

Fig. 4: Oscillogram and spectrogram of *Dundubia vaginata* song from Borneo. Since microphones were not calibrated, there is no scale on oscillogram Y-axis.

1999 and 2003 were observed, but were in our opinion not great enough to ascribe them any biological meaning.

Unknown cicada species from peninsular Malaysia. Songs of an unidentified species from peninsular Malaysia (Fig. 5), which resemble the songs of the Bornean population, are assembled from phrases, very similar in the shape of the spectrogram, but differing and varying in length. All songs have sequences of one long phrase and variable (1-5) number of short phrases. All phrases start with shorter FM part (B similar to the songs of *D. vaginata* from Borneo) and continue with CF part A with the fundamental frequency of 0.98 ± 0.01 kHz (N = 120). The fundamental frequency of the beginning of the shorter part B of the phrase is 0.91 ± 0.01 kHz (N = 120) and descends by approximately half a tone (~40 Hz). Durations of parts A and B of the longer phrase are between 1.27 s – 9.34 s and 0.12 s – 0.18 s respectively. Durations of parts A and B of the shorter phrases are between 0.30 – 1.32 s and 0.16 s – 0.21 s respectively.

Discussion

Calling songs of *D. vaginata* from Borneo and peninsular Malaysia are simple sequences of bipartite phrases, composed of one longer (A) and one shorter part (B).

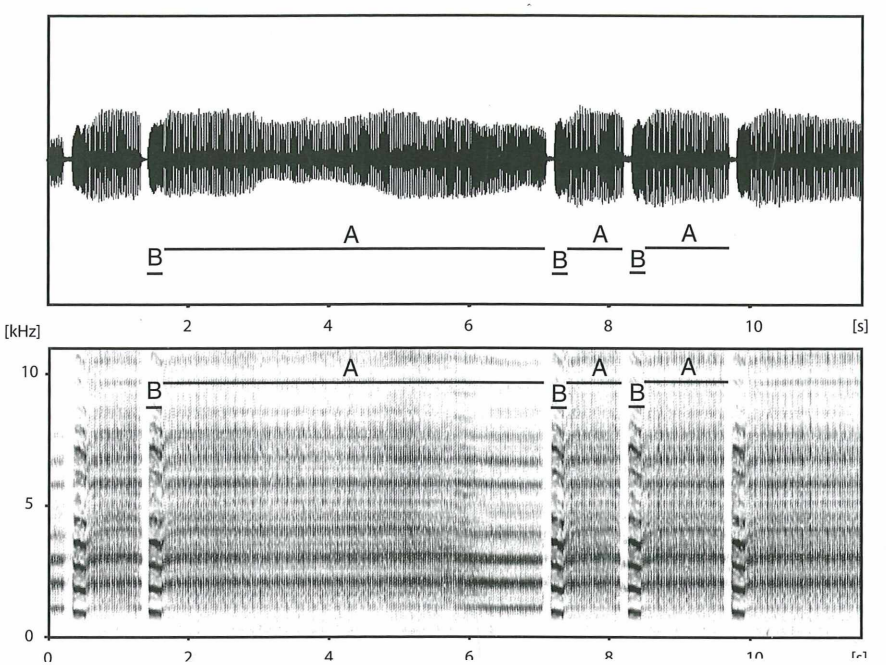

Fig. 5: Oscillogram and spectrogram of unidentified cicada's song from peninsular Malaysia. Spectrogram shapes of phrases closely resemble those of *Dundubia vaginata* from Borneo. Notice unequal length of phrases. Since microphones were not calibrated, there is no scale on oscilogram Y-axis.

But phrase parts are of different lengths, have different fundamental frequencies (more than 0.5 kHz for the longer part of phrase) and the part B of Bornean *D. vaginata* phrase is frequency modulated while the part B of the peninsular population is not – the FM occurs very quickly at the passage from the longer to the shorter part of the phrase. One should also notice different placement of the part B of the phrase in both types of calling song: at the beginning of the phrase in Bornean populations' song (Fig. 4, Tab. 1), and at the end of the phrase in peninsular populations's song (Fig. 2, Tab. 1). Riede & Kroker (1995) stated the fundamental frequencies of the shorter and longer parts of Bornean population's phrase to be at 880 Hz and 940 Hz, respectively. Their findings are not entirely consistent with ours, since their measuring of fundamental frequency was different – they have simply averaged fundamental frequencies of the shorter part. Nonetheless, our highest measured fundamental frequency (at the beginning of the part B of the phrase) is still lower than their average. In any case both sets of results from Borneo show basically the same pattern and considerable differences in comparison to the songs of *D. vaginata* from peninsular Malaysia. Observed differences in song parameters between Bornean populations' songs from years 1999 and 2003 might be ascribed to differing

ambient conditions – all recordings in the year 1999 were made during heavy rainfall (due to El Niño), which lowered temperatures, increased abiotic noise and changed sound filtering.

Tab. 1: Comparison of fundamental frequency, duration and bandwidth of both parts of songs of different populations of *Dundubia vaginata* and unknown cicada. Only data from year 2003 are shown for Bornean population.

	Long part (A) Mean ± S.D.	**Short part (B)** Mean ± S.D.	**Part succession**
Population from peninsular Malaysia			
Fundamental frequency	1.39 ± 0.03 kHz	1.08 ± 0.01 kHz	
Duration	2.3 ± 0.2 s	0.20 ± 0.03 s	A-B
Bandwith at -10 dB	0.27 ± 0.03 kHz	0.12 ± 0.01 kHz	
Population from Borneo			
Fundamental frequency	0.85 ± 0.02 kHz	0.84 ± 0.01 kHz	
Duration	1.96 ± 0.31 s	0.16 ± 0.02 s	B-A
Bandwith at -10 dB	0.20 ± 0.06 kHz	0.16 ± 0.05 kHz	
Unknown cicada from peninsular Malaysia			
Fundamental frequency	0.98 ± 0.01 kHz	0.91 ± 0.01 kHz	
Durations of the long phrase	1.27 s – 9.34 s	0.12 s – 0.18 s	B-A
Durations of the short phrases	0.30 s – 1.32 s	0.16 s – 0.21 s	

Individuals of Bornean population start singing at around 11:30 and finish at around 17:30. In this time window, their songs are dominant. They also participate later in the evening chorus, at around 18:20 – 18:30 but they are not dominant (Riede & Kroker, 1995). Gogala (Gogala & Riede 1995; see note) observed activity of peninsular population and noted that animals start to sing later, at 15:43 and they also finish later, at approximately 19:30, after joining the evening chorus. Borneo and peninsular Malaysia are in the same time zone but in respect to the sun about one hour apart. Both populations therefore share the same time window which is not so surprising, since they are closely related.

Sound communication is the principal mode of intersexual communication in cicadas and calling songs are species specific (Pringle, 1954; Ewing, 1989; Gerhardt and Huber, 2002). Hence it is very likely that observed significant differences in songs of Peninsular and Bornean populations would render communication between their members impossible. Cases of species complex, consisting of morphologically undistinguishable species, but well characterized by bioacoustics, ecology and behaviour are already known among cicada species (e. g. Gogala and Trilar, 2004). Our work supports morphological differences already found by Overmeer and Duffels (1967). Since Duffels after additional surveying of material did not find

differences in opercule length great enough to use them as a discriminating character (personal communication, 2003), additional researches, both bioacoustical and morphological, will have to be done. We also expect to support our results with genetical analyses. In the future we also intend to investigate material from *locus typicus* in Sumatra.

Songs of an unidentified cicada species from peninsular Malaysia do resemble songs of *D. vaginata* from Borneo, but without morphological identification we can only assume that this unidentified cicada is closely related to *D. vaginata*, especially to the Bornean population.

Note

In the paper of Gogala & Riede (1995) the song of *Dundubia vaginata* has been preliminary attributed to the *Maua* sp. by the first author (MG). Further investigations and recordings of captured cicadas in the year 1999 and following years have clearly shown that in peninsular Malaysia this song pattern is without any doubt emitted by peninsular *D. vaginata*.

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