Description of the song of *Purana metallica* from Thailand and *P. latifascia* from Borneo (Hemiptera, Cicadidae)

Matija Gogala & Tomi Trilar

Songs of cicadas *Purana metallica* Duffels & Schouten, 2007 and *P. latifascia* Duffels & Schouten, 2007 were investigated. The structure of 50 to 95 s long calling song of *P. metallica* is a complicated but more or less regular sequence of long and short echemes combined with short clicks. The song sequence starts, after some accelerated pairs of short clicks, with a frequency modulated very long echeme of buzzing sound, which becomes interrupted into a series of short echemes and follows with a series of short echemes interrupted by longer pauses and dividing the song into groups of short echemes and later into groups of short echemes and clicks. The high-pitched calling song of *P. latifascia* consists of long repeated phrases (duration 110 to 150 s). The frequency modulated introductory phrase is followed by 3 to 4 repeating phrases, which start with a frequency constant buzzing sound, pass over into vibrato sequences and end with a frequency modulated pulsating sound.
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Introduction

Duffels et al. (2007) presented a revision of the *Purana tigrina* species group in Sundaland. *Purana tigrina* (Walker, 1850) and five new species were identified, named and described. It would be a great advantage, if we could describe also the songs of all six species of the group, since calling songs of cicadas are highly species specific and of a great help for the recognition of hidden sister species (e.g. Puissant & Boulard 2000, Gogala & Trilar 2004, Prešern et al. 2004, Gogala 2006). A knowledge of song patterns is very useful also in biodiversity investigations and monitoring of faunal changes.

Currently we know from this species group only the songs of *Purana metallica* Duffels & Schouten, 2007 and *Purana latifascia* Duffels & Schouten, 2007. *Purana metallica* is known from southern Thailand and Langkawi Island (Malaysia), *P. latifascia* occurs in eastern Sabah, Borneo. The main characteristics of the calling song of *P. metallica* have been already described as *Purana* aff. *tigrina* from Ko Tarutao, Thailand (Gogala 1995). Here we give the description of the song of *P. latifascia* and a more detailed description of the song of *P. metallica* with emphasis on time parameters and some other details.

Material and methods

Songs were recorded in the field using a parabolic stereo microphone Telinga Pro III (parabola diameter 57 cm) connected to Sony dat-recorder TCD-D3 (sampling rate 48 kHz, 16 Bit dynamic range). In the lab, dat recordings were transferred to the Hard Disk of a Power Macintosh G4 computer through an Audiomedia III sound card. For viewing, editing and analysing the song signals we used Pro-Tools 5.0 (Digidesign, Avid Technology), and Raven 1.2 software (Cornell Lab of Ornithology). For

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statistical evaluation we used Microsoft Excel.
Three males of *P. metallica* and two males of *P. latifascia* were first recorded and then collected. In addition also one female of *P. metallica* was collected. These specimens are presented as paratypes in Duffels et al. (2007). They are deposited in the collection of the Slovenian Museum of Natural History (PMSL) in Ljubljana. All sound recordings are stored in the Sound Archive of the Slovenian Museum of Natural History. The samples of the song are available on the web page:
http://www2.pms-lj.si/staff/bioacoustics/asian.html

Results

Purana metallica Duffels & Schouten

Purana metallica males were observed and collected, and their "metallic" sounds were recorded during an expedition to the island Ko Tarutao off the SW coast of Thailand (Satun province) and in the Thale Ban National Park (written also as Thaleban, Taleban or Talaban) near the Thai-Malaysian border in the period of 13–18 April 1993. In Thale Ban we were not able to collect any specimen but the song pattern recorded is without any doubt identical with that of *P. metallica* from Ko Tarutao. The analysis of the sound emission is based on seven complete songs and some fragments (only beginning or end) of four different individuals. The insects were observed in the lower stratum of the rainforest and also in forest clearings and on trees at the seashore. Temperature measured during the recordings on Ko Tarutao was 31 ± 2ºC and in Thale Ban 29ºC.
The structure of this calling song is a complicated but more or less regular sequence of long and short echemes combined with short clicks. The song pattern changes with time in a characteristic way from the beginning to the end of the song, the duration of which is 50–95 s. The song sequence starts after some accelerated pairs of short clicks (see Fig. 1) with a very long echeme (VLE) of buzzing sound (Fig. 1, 2a-c), lasting between 6 and 14.5 s (mean and standard deviation: 11 ± 3.6 s, N=7).
Then the buzzing sound becomes interrupted into a series of short echemes (SE) with 24–39 ms duration (median values) at the beginning. After some seconds the duration of SE slowly decreases to 21–25 ms. The duration of intervals between echemes increases exponentially and the resulting repetition rate of SE is slowly decreasing from about 15 SE/s to less than 10 SE/s (Fig. 3).
In the following phases of the song the series of SE is interrupted by longer pauses, lasting 0.3–1.4 s (0.52 ± 0.18 s, N=63) and dividing the song into groups of SE and later into groups of SE and clicks (Fig. 1). The duration of SE in the next groups of echemes stabilizes around 20–25 ms and the SE-SE intervals inside the groups of echemes remain more or less the same. Therefore, the repetition rate of SE remains about 4.5–6 SE/s during the next phases of the song.
Finally, short clicks (duration 2–4 ms) appear in the SE-SE intervals. Clicks, probably produced by a single activation of one tymbal, appear usually in pairs but also as single events (Fig. 2d-f). The delay between double clicks can be as short as 5 ms but in most cases is around 10 ms. Double clicks are divided by longer pauses of approximately 20–26 ms and single clicks are separated by even longer intervals. Therefore the intervals between clicks or clicks and short echemes are concentrated in three or more peaks in histogram (Fig. 4). The very short and variable delay in double clicks supports our assumption that such pairs are produced by subsequent and alternated activation of left and right tymbals.
The number of clicks in each SE-SE interval increases towards the end of the song in each group of echemes to 6 or even 8 double clicks. The song sequence ends with long series of click pairs, which slowly fade out due to decreasing intensity.
The new song starts after a somewhat longer pause of about 650 ± 160 ms (N=6).
As described already in a previous paper (Gogala 1995), the frequency spectrum of the song has a fundamental frequency at about 2.35–2.48 kHz with pronounced 4 higher harmonics and further 6 or more harmonic peaks of lower intensity (-40 dB). The dominant frequency in all phases of the song is the 3rd higher harmonics at 9.10–9.80 kHz. During the VLE we observe a characteristic slow frequency modulation. The fundamental frequency is at the beginning of VLE between 2.26–2.32 kHz and increases slowly towards the end of this very long echeme to 2.33–2.45 kHz (for 2.6–8.4%). Higher harmonics inclusive dominant frequency follow this frequency shift reaching in some recordings 9.80 kHz at the dominant frequency peak.

Purana latifascia Duffels & Schouten

The analysis of the sound emission of *P. latifascia* is based on five complete songs and some fragments (only beginning or end) of four different individuals recorded on 2 May 1999 around 14.00 in Kampong Lubu (Borneo: Malaysia: Sabah: Klagan, Kampong Lubu; 06°02' N; 117°34' E). It is a village of dispersed long houses at the border of mangroves along the river Sungai Klangan, 3 to 7 km away from the sea. The ambient temperature was 31.6ºC. Two of

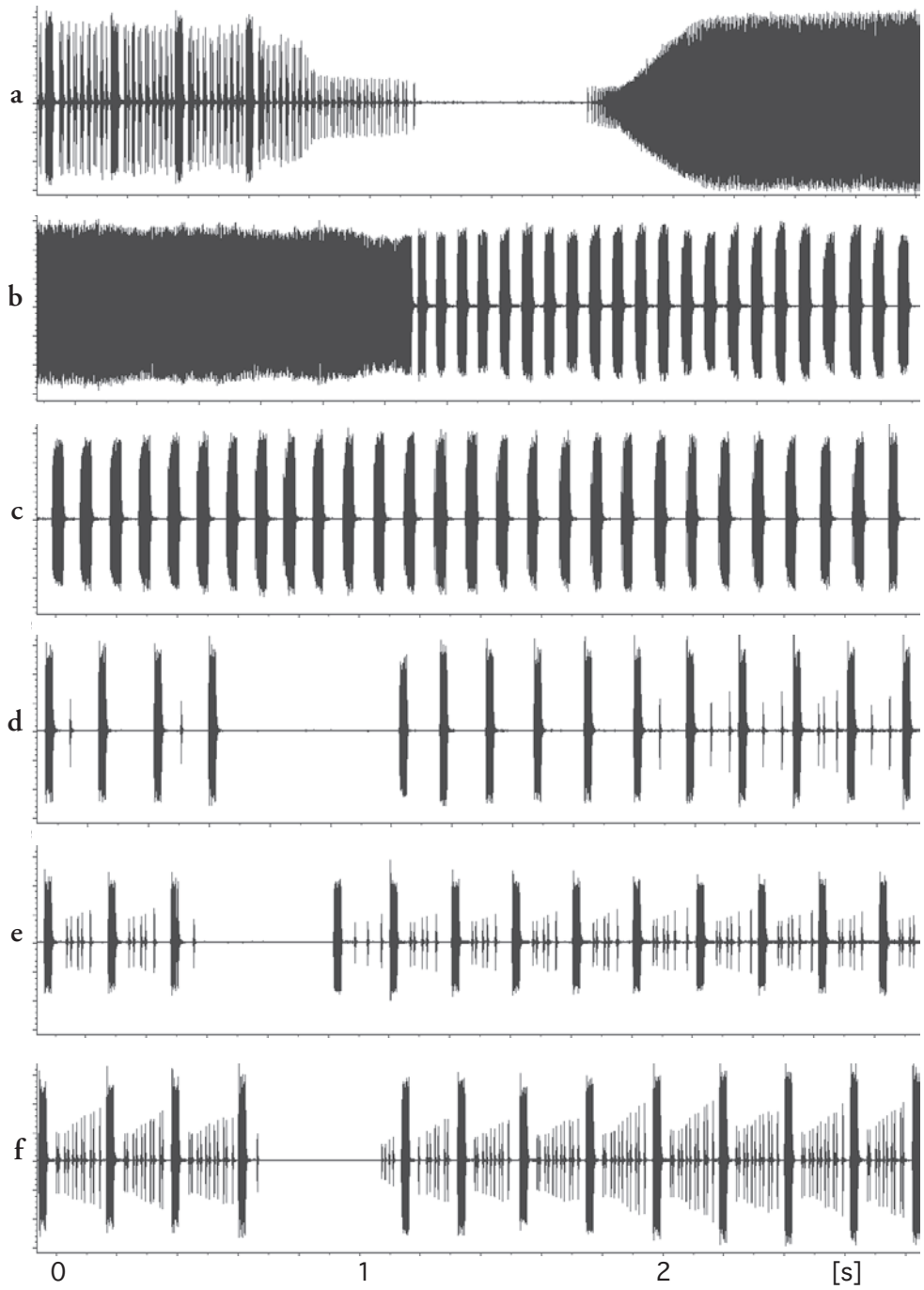

Fig. 1. Song of *Purana metallica* from Ko Tarutao, Thailand. – Oscillograms of the: a) last part of the song with four short echemes (SE) and series of clicks and the beginning of a new sequence with very long echeme (VLE), b) the end of VLE with series of short echemes, c) series of short echemes with decreasing repetition rate, d) first clicks appearing in SE-SE intervals and pauses between groups of SE and clicks, e) increasing number of clicks and pairs of clicks during a later phase of song, f) the number of clicks and double clicks is in later stage even higher and ends with highest number of clicks towards the end of a song as shown in a. Time scale is shown below.

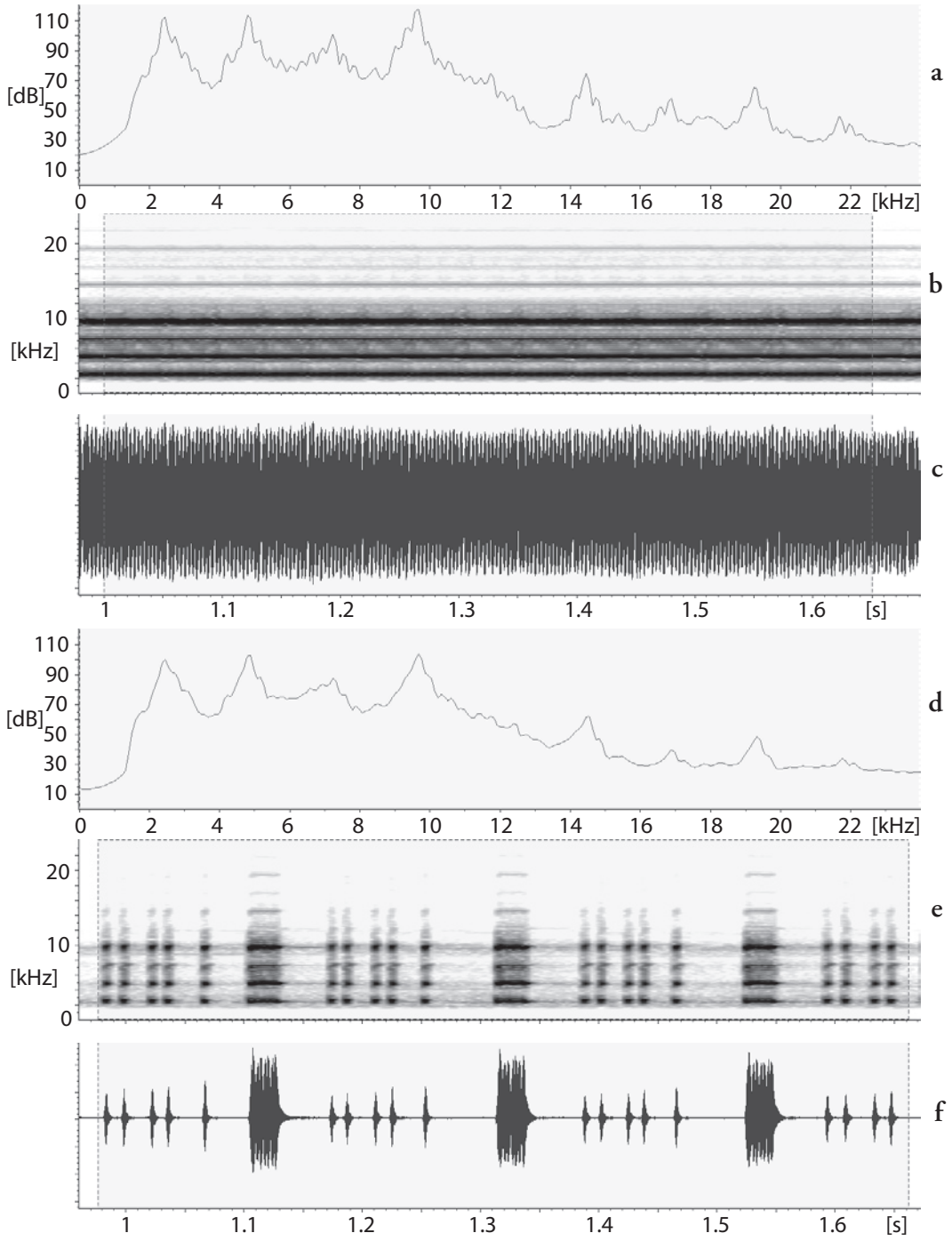

Fig. 2. Song of *Purana metallica*. – Sound spectra (a & d), spectrograms (b & e) and oscillograms (c & f) of a part of VLE (a-c) and a selection with SE and clicks (d-f). Side bands can be clearly seen in a) due to amplitude modulation (series of clicks), seen in c). Peaks of frequency components above 12 kHz are for about 40–50 dB lower than in the range between 2–10 kHz.

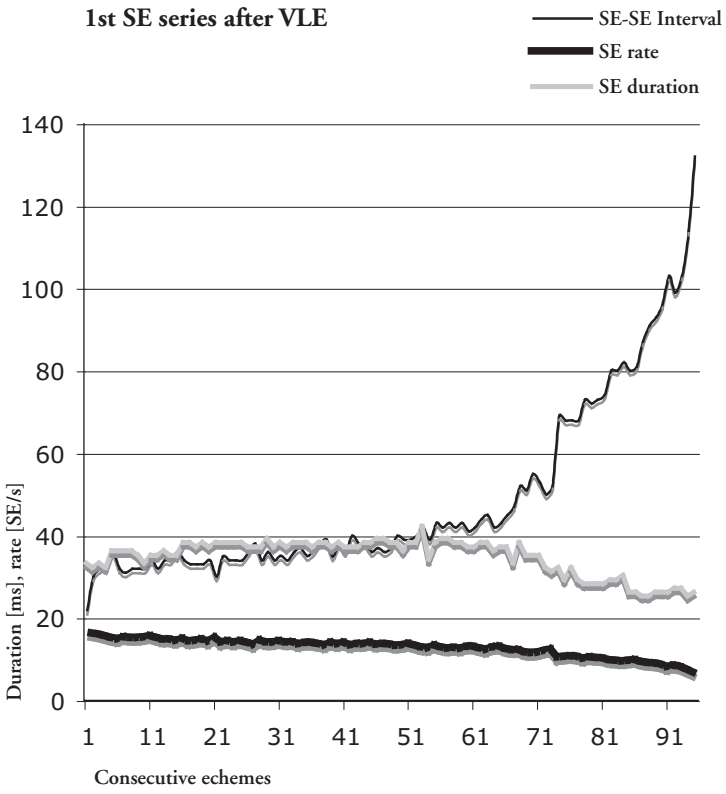

Fig. 3. Song of *Purana metallica*. – Graph showing the typical changes of SE duration, SE-SE interval and repetition rate of SE during the first group of SE after the long buzzing sound VLE.

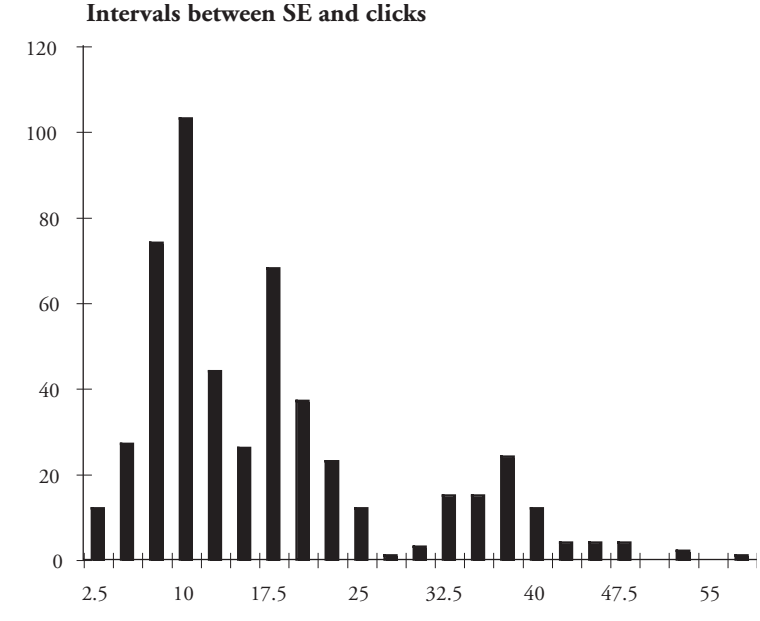

Fig. 4. Song of *Purana metallica*. – Histogram of intervals between SE and clicks in a selected part of a song, similar to selection shown in Fig. 1e & 1f. The highest values are for intervals between pairs of clicks around 10 ms and for single clicks around 18 ms.

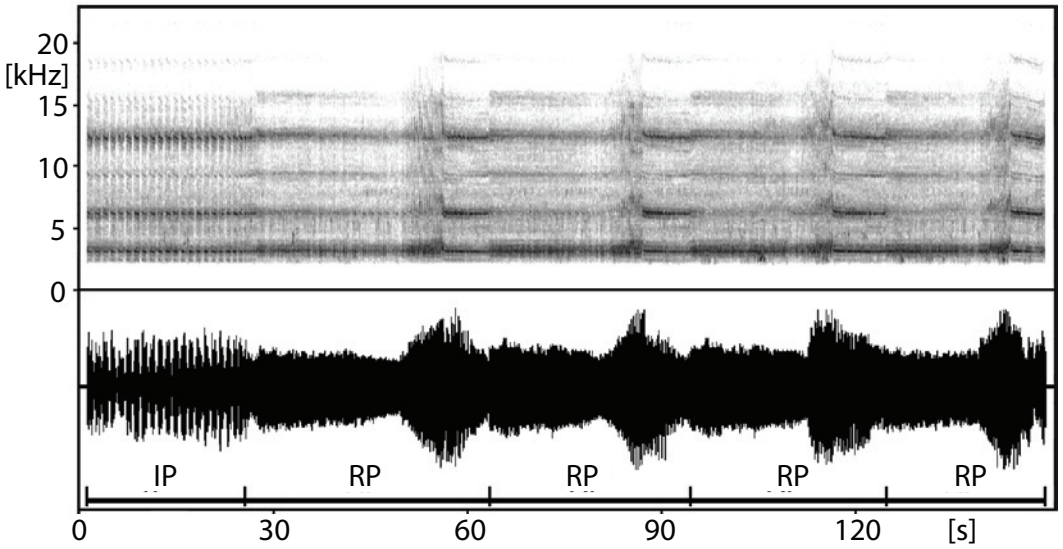

Fig. 5. Song of *Purana latifascia* from Kampong Lubu, island Borneo, Sabah, Malaysia. – Spectrogram and oscillogram of a typical song (IP – introductory phrase - expanded on Fig. 6; RP – repeating phrase - expanded on Fig. 7).

the singing males were also collected after the recording and are presented as type material in Duffels et al. (2007).

The high-pitched calling song of *P. latifascia* consists of long repeated phrases (duration 134.9 ± 15.9 s, range 111.4–150.9 s, N=5). After a 2.3 s long pause (N=1), the male starts calling again or flies to another tree and calls from this place again.

The song sequence can be divided into two main parts or phrases (Fig. 5). The introductory phrase (IP) (Fig. 6) is followed by 3 to 4 repeating phrases (RP) (Fig. 7).

In 24.6 to 62.8 s long IP (Fig. 6a) there are 22 to 35 frequency modulated echemes (duration 751 ± 54 ms, range 638–854 ms, N=129) separated by intervals of 413 ± 34 ms (range 312–479 ms, N=115) (Fig. 6b). In intervals there are series of clicks (duration 2.34 ± 0.48 ms, range 1.47–3.57 ms, N=49) following each other irregularly. Last 7 (3–7) echemes and intervals are becoming rapidly shorter (Fig. 6a) and are without a pause switching to RP.

The echemes are frequency modulated (Fig. 6b). The major part of sound energy is between 2.5–13 kHz. The frequency at the beginning of the echeme slowly decreases to the frequency at the end of the echeme for 2.9–3.0% (long sweep down). Dominant is the 3rd higher harmonic frequency, followed by the fundamental frequency (beginning of echeme 3.13 ± 0.05 kHz, end 3.04.5 ± 0.05 kHz) and the 1st higher harmonic, while the 2nd and 4th higher harmonics are less prominent and the 5th higher harmonic is often completely masked by the noise from the environment. In IP echemes the occurrence of so called side bands of the spectral peaks is also very obvious. The distance of the side bands in sonograms is around 375 Hz (Fig. 6a, b). These sidebands are the consequence of the amplitude modulation of basic sound units – single tymbal clicks or groups of clicks. The distance of the sound band peaks in the spectrum compared to the frequency of the main peak corresponds to the frequency of the amplitude modulation.

Repeating phrases (RP) occur 3 (N=2) to 4 times (N=3) inside one phrase (Fig. 5). Each RP consists of 3 subphrases (Fig. 7) and is 30.6 ± 4.7 s long (range 22.5–41.3, N=17). It starts with frequency constant buzzing sound (BS) (Fig. 8), which passes over into vibrato sequence (VS) (Fig. 9) and ends with pulsating sound (PS) (Fig. 10).

Subphrase with frequency constant buzzing sound (BS) is the only frequency constant part of *P. latifascia* song (Fig. 8). Duration of BS is 18.1 ± 3.2 s (range 14.2–26.1 s, N=17). The beginning of BS (Fig. 8b) is composed of 94 ± 11 clicks per second (range 77–108, N=16) (measured in one second long period at the beginning of the BS). The end of the subphrase (Fig. 8c, d) is built from single-click – double-click units with repetition rate 18.3 ± 1.9

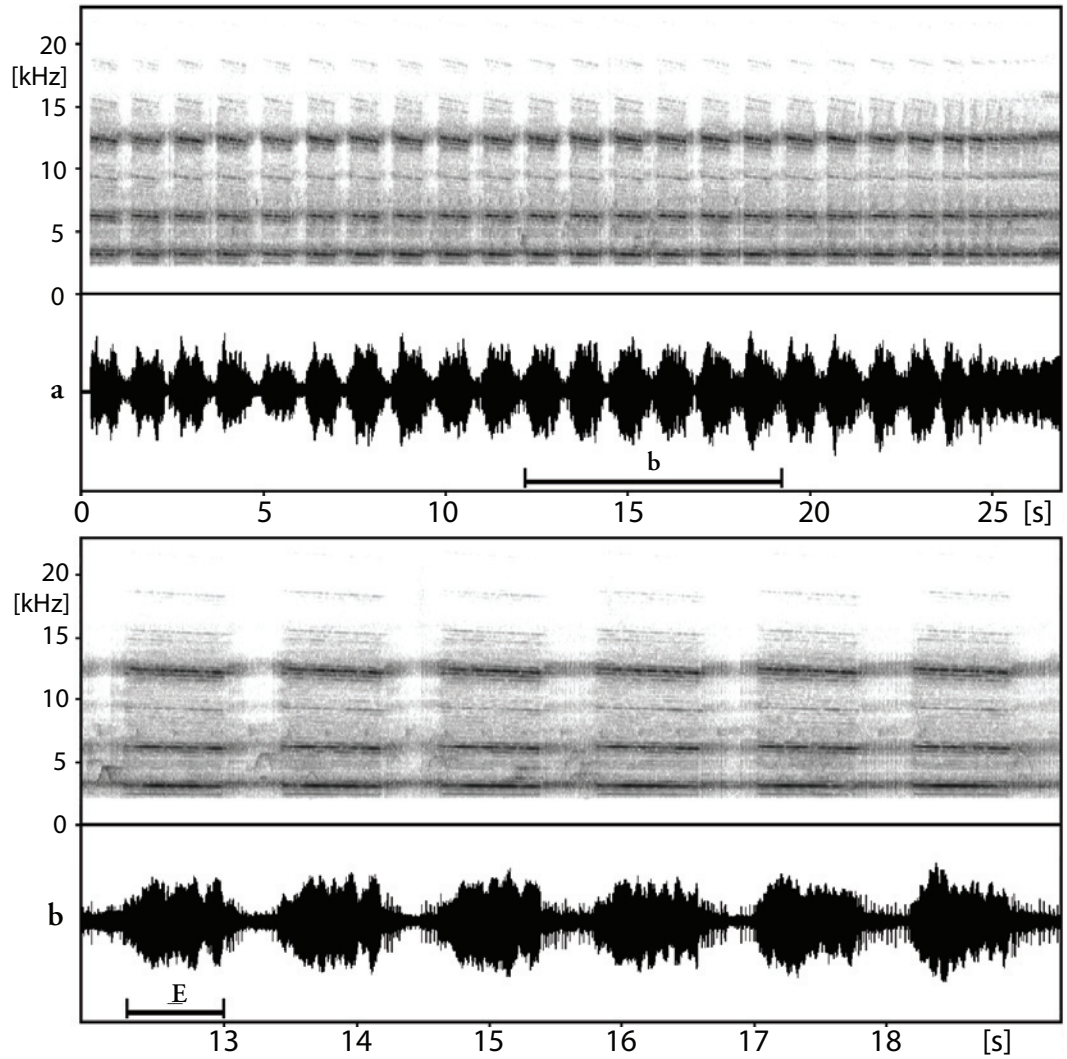

Fig. 6. Song of *Purana latifascia*. – (a) Spectrogram and oscillogram of introductory phrase (IP) of the song (b – part enlarged in section *b* of the figure). (b) Spectrogram and oscillogram of 5 frequency modulated echemes (E – echeme).

(range 16–23 units per second, N=12) (measured in one second long period at the end of the BS). In this units the single-click duration is 2.7 ± 0.5 ms (range 1.7–4.0 ms, N=132), double-click duration is 5.2 ± 0.6 ms (range 4.1–6.7 ms, N=135). The distance between clicks in double-clicks is 2.6 ± 0.5 ms (range 1.6–3.7 ms, N=122). The interval between single-click and double-click is 12.0 ± 3.4 ms (range 3.2–18.4 ms, N=138) and the interval between single-click – double-click units is 39.6 ± 6.0 ms (range 21.0–51.9 ms, N=134).

Dominant are the fundamental frequency (3.13 ± 0.06 kHz) and the 3rd higher harmonic (measured at the beginning of the subphrase), followed by the 1st higher harmonic, while the 2nd and 4th higher harmonics are less prominent and the 5th higher harmonic is often completely masked by the noise from the environment. The major part of sound energy is between 2.5–13 kHz.

Vibrato in music is described as sequence of repeating minute and rapid variations in pitch over a short time period of the sound. Subphrase with vibrato

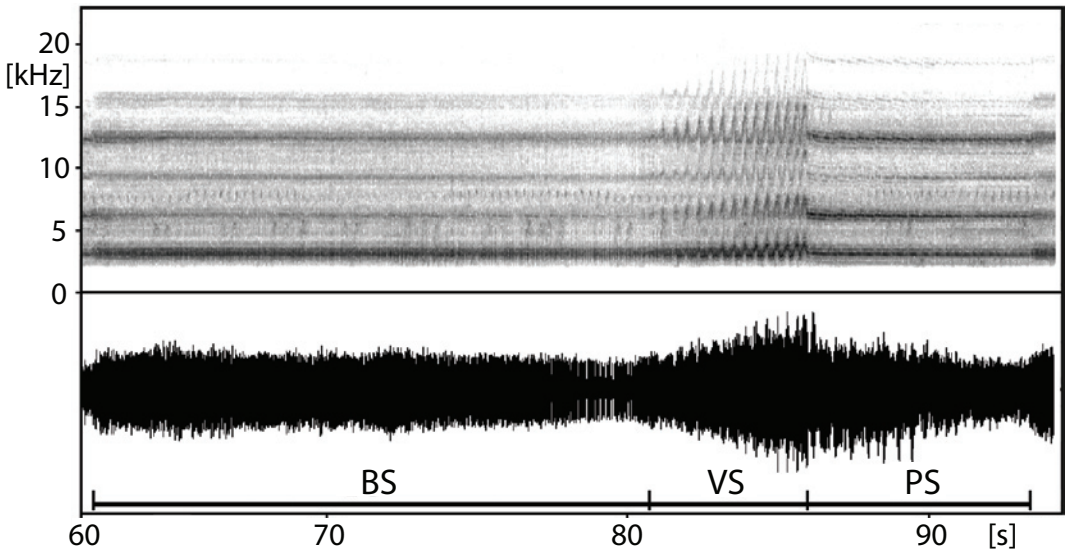

Fig. 7. Song of *Purana latifascia.* – Spectrogram and oscillogram of repeating phrase (RP) of the song (BS – subphrase with frequency constant buzzing sound - expanded on Fig. 8; VS – subphrase with vibrato sequence - expanded on Fig. 9; PS – subphrase with pulsating song - expanded on Fig. 10).

sequence (VS) lasts 5.5 ± 0.9 s (range 4.1–7.2 s, N=18) and consists of 15 ± 2 frequency modulated parts (FM) (range 13–19, N=17) of quickly raised and lowered frequencies (Fig. 9). The VS starts with a small FM, which are getting more and more distinctive. Duration of the last 10 FM preceding the last but one is 194.1 ± 19.5 ms (range 137.7- 242.7 ms, N=180) with 160.5 ± 32.2 ms long frequency constant part (FC) (range 99–250 ms, N=170) in-between. The last FC (58.1 ± 31.3 ms, range 16–136 ms, N=17) and the last FM (duration 238.0 ± 41.7 ms, range 126.9–297.9, N=18) are shorter (Fig. 9b).

The fundamental frequency of the FC is 3.08 ± 0.07 kHz (range 3.00–3.19 kHz, N=17), then the fundamental frequency quickly raises to 3.80 ± 0.07 kHz (range 3.66–3.94 kHz, N=17) at the peak of FM and immediately drops to the same level in the new FC (measured at FC and FM preceding the last but one). Difference between fundamental frequencies of FC and the peak of FM is 16.5–18.9% (approximately three tones). Dominant is the fundamental frequency, followed by the 1st and 3rd higher harmonics, while the 2nd and 4th higher harmonics are less prominent and the 5th higher harmonic is often completely masked by the noise from the environment. The major part of sound energy is between 3–16 kHz.

The last FM of VS continuously pass over to the first echeme of subphrase with pulsating song (PS) (Fig. 10). PS subphrase lasts 7.6 ± 1.6 s (range 3.2-9.4 s, N=14) and consists of 19 ± 2 frequency modulated echemes (range 16–21, N=13). Duration of the first echeme is 1021 ± 103 ms (range 897–1242 ms, N=18) and of the second one 627 ± 125 ms (range 433–1003 ms, N=17). Each following echeme is shorter. The duration of the echeme preceding the last but one is 226 ± 38 ms (range 189–343 ms, N=14) and of the last one is 219 ± 74 ms (range 138–365 ms, N=14). The duration of the interval between the echemes is 30 ± 14 ms (range 11–68 ms, N=244). The song's last PS is shorter (duration 5.6 ± 0.5 s, range 5.4–6.4 s, N=4).

The echemes are frequency modulated. The major part of sound energy is between 2.5–14 kHz. The frequency at the beginning of the echeme slowly decreases to the frequency at the end of the echeme for 2.5–3.7% (long sweep down). Dominant are the fundamental frequency (beginning of echeme 3.12 ± 0.04 kHz, end 3.11 ± 0.04 kHz), the 1st and 3rd higher harmonics, while the 2nd, 4th and 5th higher harmonics are less prominent and the 6th higher harmonic is often completely masked by the noise from the environment. In VS echemes is also very obvious the occurrence of so called side bands of the spectral peaks. The distance of the side bands in sonograms is around 375 Hz (Fig. 10).

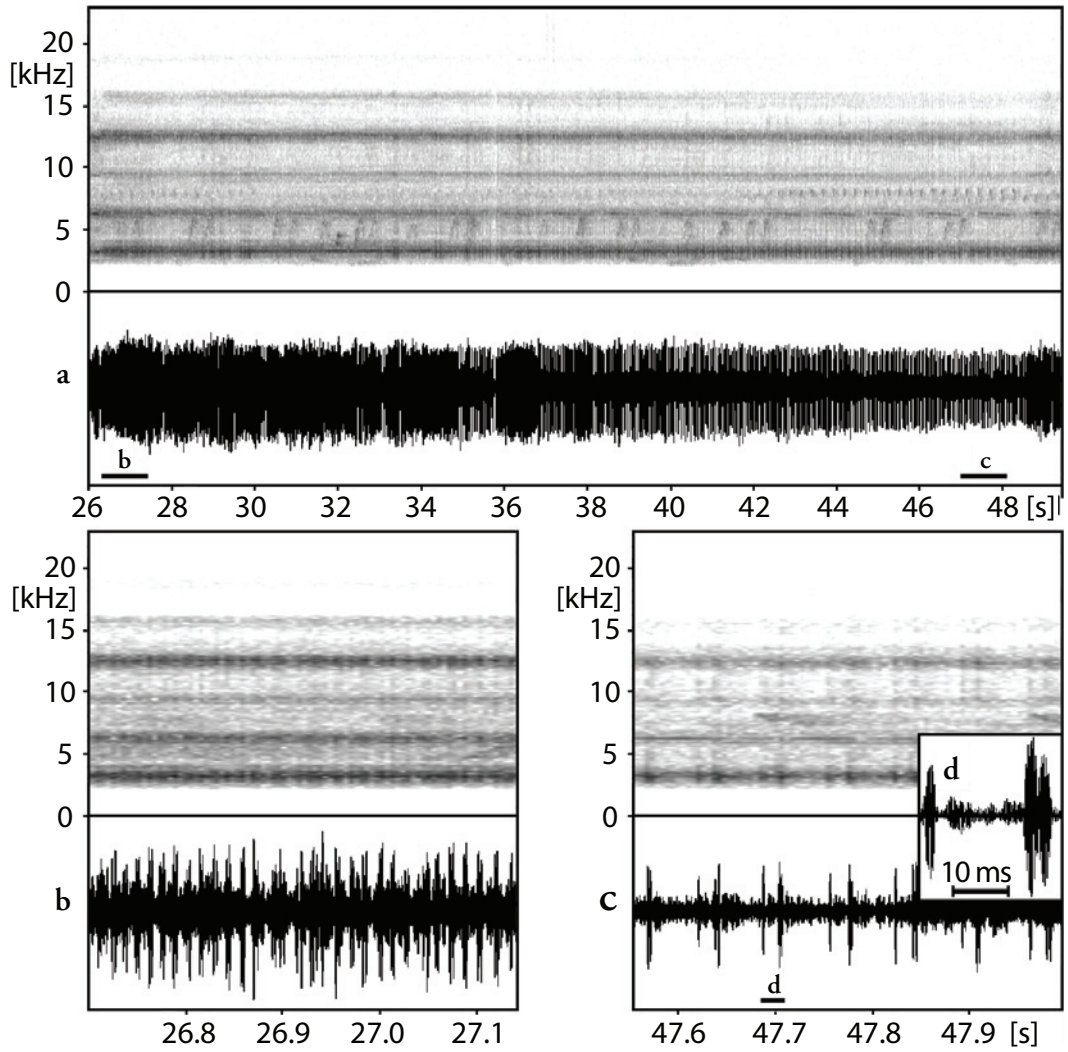

Fig. 8. Song of *Purana latifascia*. – (a) Spectrogram and oscillogram of subphrase with frequency constant buzzing sound (BS) of repeating phrase (RP) (b – part enlarged in section *b* of the figure; c – part enlarged in section *c* of the figure). (b) Spectrogram and oscillogram of the beginning of BS. (c) Spectrogram and oscillogram of the end of BS, which is built from single-click – double-click units (d – expanded part from Fig. 8d). (d) Single-click – double-click unit.

Discussion

According to our knowledge the song of *Purana tigrina* s. str. is not known. The only paper describing the song of *P. tigrina* was published recently by Boulard (2006). However, a comparison of the Boulard's specimens from Northern Thailand with the material investigated by Duffels et al. (2007) showed that Boulard's specimens do not belong to the *tigrina*-group (J.P. Duffels, personal communication). Nevertheless, sound emissions of a number of *Purana* species have been described till now. Probably the first description of the song of any *Purana* species has been published by Pringle (1954, *P. campanula* Pringle, 1955). More recently the sound emissions of the following species have been described: *P. nebulilinea* (Walker, 1868) (Kos & Gogala 2000), *P. sagittata* Schouten & Duffels, 2002 (Trilar & Gogala 2002), *P. khuniensis* Boulard, 2005 (Boulard 2005a), *P. johanae* Boulard, 2005, *P. doiluangensis* Boulard, 2005, *P. jdmoorei* Boulard,

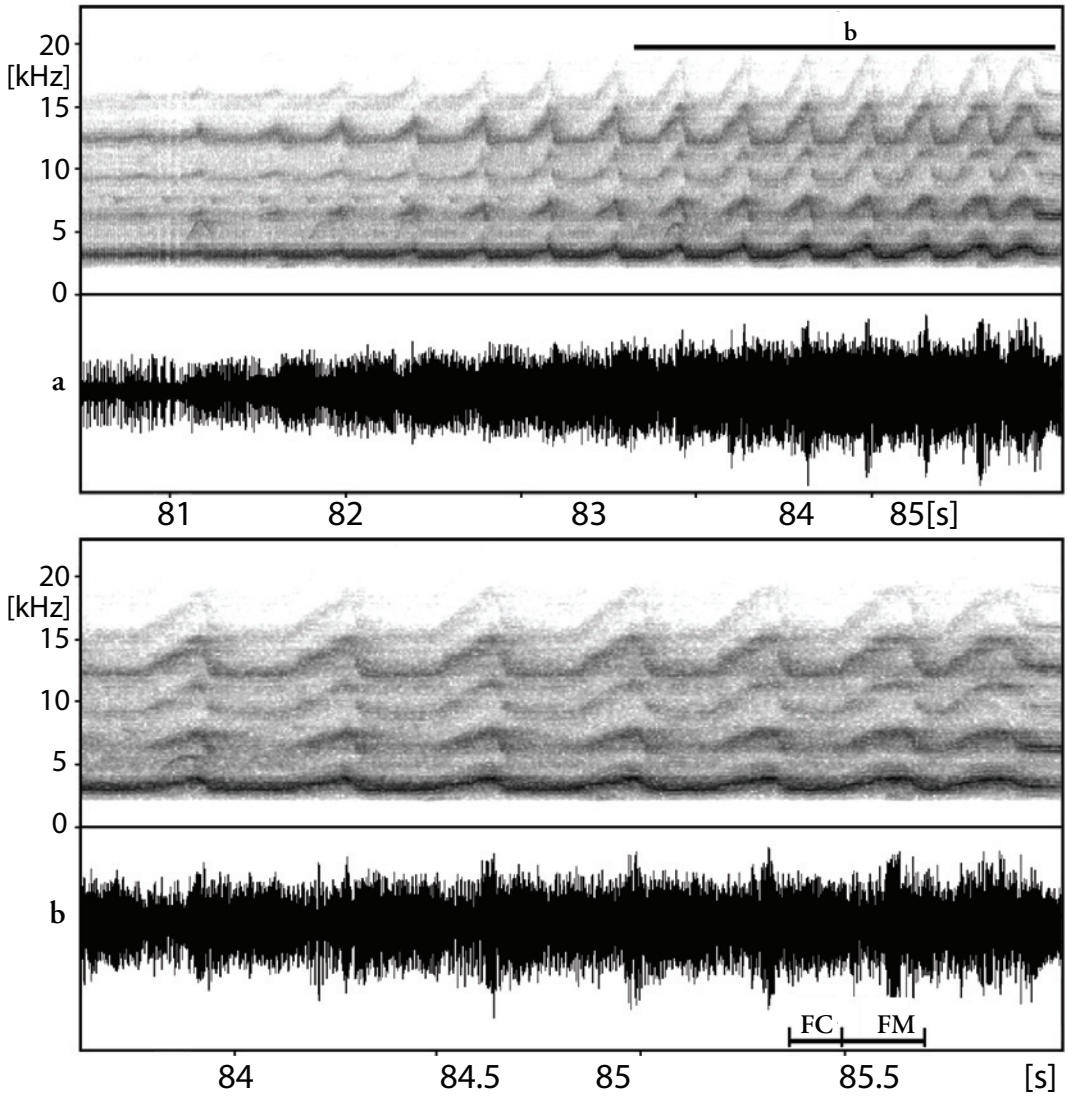

Fig. 9. Song of *Purana latifascia*. – (a) Spectrogram and oscillogram of subphrase with vibrato sequence (VS) of repeating phrase (RP) (b – part enlarged in section *b* of the figure). (b) Spectrogram and oscillogram of last 7 FM (FM – frequency modulated part; FC – frequency constant part).

2005 (Boulard 2005b) and *P. atroclunes* Boulard, 2002 (Boulard 2002).

According to our knowledge the song patterns described for *P. metallica* and *P. latifascia* are unique and easily discernible from all other species of the genus *Purana* investigated till now. However, the two species have some characteristics in common, as the frequency spectra with four or more main harmonic frequency peaks, 2nd higher harmonic being less prominent and dominant frequencies usually around 9–13 kHz (3rd higher harmonic). Also the frequency modulated parts of the song and the long, complicated sequences of songs with different phrases are characteristic.

We found similarity between the song of *P. metallica* and *P. doiluangensis* (Boulard, 2005b), but the song phrase of the latter is only about 15 s long and much simpler, resembling just a first group of echemes of

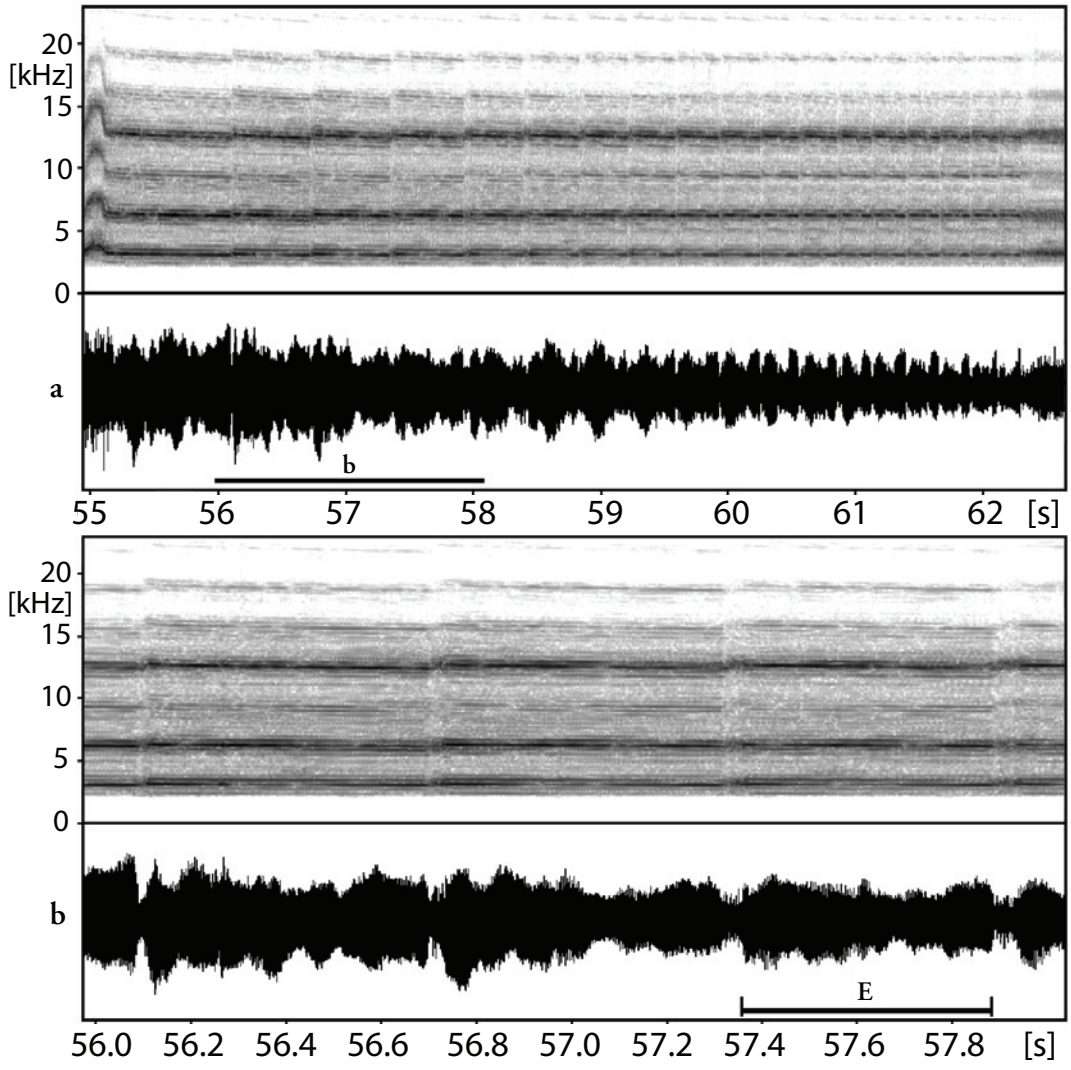

Fig. 10. Song of *Purana latifascia*. – (a) Spectrogram and oscillogram of subphrase with pulsating song (PS) of repeating phrase (RP) (b – part enlarged in section *b* of the figure). (b) Spectrogram and oscillogram of 3 frequency modulated echemes (E – echeme).

the first species. In the song of *P. latifascia*, however, one can find some similarities with the sound emissions of *P. nebulilinea* (Kos & Gogala 2000).

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