**PAGIPHORA ASCHEI KARTAL (HEMIPTERA: CICADIDAE) FROM CRETE (GREECE) – DISTRIBUTION AND DESCRIPTION OF ITS SONG**Tomi TRILAR¹ and Matija GOGALA²

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Abstract – Using recording equipment for sonic range we recorded the calling song of *Pagiphora aschei* Kartal 1978 that can be found in the Greek island of Crete and in the Antalya Province of Turkey. In Crete, *P. aschei* is widely distributed and common from the seacoast up to 600 m a.s.l. Nevertheless, the song of this species had not been described until now. The calling song structure is characteristic and easily distinguishable from the songs of related cicadas. Typical for the calling song are two song patterns, monotonous repetition of short echemes and continuous song. The calling song is made of three phrases (A, B, C). Phrase A consists of short echemes, phrase B has an introductory part of continuous song, which switches without any interruption to sequence of short echemes, and phrase C consists of continuous song with characteristic amplitude envelope. This species-specific calling song pattern is compared with known songs of other *Pagiphora* species.

KEY WORDS: *Pagiphora aschei*, Cicadidae, calling song, bioacoustics, singing cicadas, Mediterranean basin

Izvleček – PAGIPHORA ASCHEI KARTAL (HEMIPTERA: CICADIDAE) S KRETE (GRČIJA) – RAZŠIRJENOST IN OPIS NJENEGA NAPEVA

S pomočjo snemalne opreme za slušno območje smo posneli pozivni napev škržada vrste *Pagiphora aschei* Kartal 1978, ki je razširjena na grškem otoku Kreta in v Antaliji v Turčiji. Na Kreti je vrsta splošno razširjena in pogosta od morske obale do nadmorske višine 600 metrov. Kljub temu oglašanje te vrste še ni bilo opisano. Struktura napeva je vrstno značilna in jo po pozivnem napevu zlahka ločimo od napevov sorodnih po-

jočih škržadov. Značilna za pozivni napev sta dva zvočna vzorca, enakomerno ponavljanje kratkih ehemov in neprekinjeni napev, ki tvorita tri fraze (A, B, C). Za frazo A je značilno enakomerno ponavljanje kratkih ehemov, medtem ko frazo B sestavljata uvodni neprekinjeni napev in sosledje kratkih ehemov, ki se brez prekinitve nadaljujejo iz njega. Frazo C sestavlja neprekinjen napev z značilno amplitudo ovojnice. Vrstno značilni pozivni napev sva primerjala tudi z drugimi pojočimi škržadi istega rodu.

KLJUČNE BESEDE: *Pagiphora aschei*, Cicadidae, pozivni napev, bioakustika, pojoči škržadi, Sredozemlje

Introduction

There is still no comprehensive paper on the singing cicadas (Cicadidae, *sensu* Moulds 2005) of Greece, but several recent papers improved the taxonomy of Greek cicadas. We published the description of one new genus and species *Euboena castaneivaga* Gogala, Trilar & Drosopoulos 2011 (Gogala et al. 2011) with its song. We described also four new species of “mountain cicadas”, all endemic to Greece: *Cicadetta hannekeae* Gogala, Drosopoulos & Trilar 2008, *Cicadetta olympica* Gogala, Drosopoulos & Trilar 2009, *Cicadetta kissavi* Gogala, Drosopoulos & Trilar 2009 and *Cicadetta dirfica* Gogala, Trilar & Drosopoulos 2011 (Gogala et al. 2008, 2009, 2011) with acoustic data.

We recorded for the first time and analysed the song of *Cicadivetta carayoni* (Boulard 1982) (Trilar & Gogala 2010), a species endemic to Crete. Only recently another species endemic to Crete, *Cicada cretensis* Quartau & Simões 2005, has been described together with its song characteristics (Quartau & Simões 2005). The third cicada species present in Crete is *Pagiphora aschei* Kartal 1978, which can also be found in Antalya Province of Turkey (Kartal 1983, Demir 2007, 2008) (Fig. 2). However, the song of *Pagiphora aschei* had not been previously investigated (Sueur 2001) and had not been described yet.

Pagiphora aschei (Fig. 1) was originally described on the basis of a single male collected in Agia Galini (Crete) on July 20th, 1976 by Manfred Asche (Kartal 1978). The type is deposited in the Museum für Naturkunde in Berlin, Germany.

In this paper, we give new distribution data, show for the first time the song characteristics, and provide some behavioural and ecological informations on *P. aschei*.

Material and Methods

We investigated the singing cicadas (Hemiptera: Cicadidae) of the Greek island of Crete (Kriti) with bioacoustic methods in 2003, 2005 and 2006. From August 8th to 22nd, 2003, August 6th to 20th, 2005, May 27th to June 3rd, 2006 and August 5th to 19th, 2006 we visited Hanya, Rethymno, Iraklio and Lasithi Counties (Nomos Chanion, Nomos Rethymnou, Nomos Irakliou, Nomos Lassithiou).

For sound recordings we used microphones, sensitive in sonic range (Telinga Pro 5 and 6 stereo - parabola diameter 57 cm) in combination with Sony DAT recorder TCD-

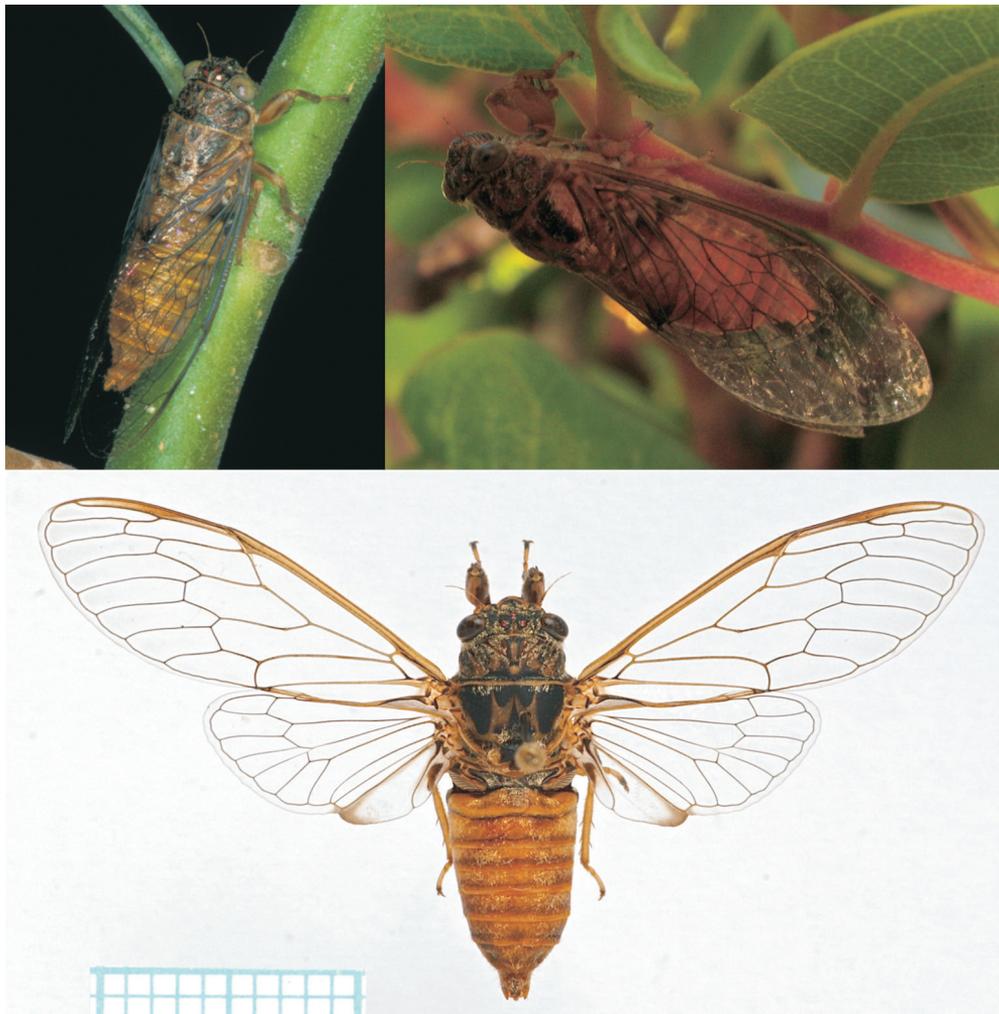


Fig. 1: *Pagiphora aschei*. Live animal from Platania photographed on 15. 8. 2003 (left) and Balos photographed on 17. 8. 2006 (right) and prepared male specimen (below).

D3 and solid state recorders Marantz PMD660 and PMD670. We perform the measurements on the original left channel of the stereo Telinga microphone. For the analysis of acoustic data we use computer programs Raven 1.3 (Cornell Lab of Ornithology) and Seewave package (Sueur et al. 2008) as a part of R software platform (R Development Core Team 2008).

The specimens collected are preserved in the collection of the Slovenian Museum of Natural History (PMSL) in Ljubljana, Slovenia. All sound recordings are stored in the Slovenian Wildlife Sound Archive housed in PMSL. Representative sound sam-



Fig. 2: Distribution of *Pagiphora aschei*. Red dots - data from this work, blue dots - according to Kartal (1983) and Demir (2007, 2008). The map is created by GPS Visualizer (Schneider 2003-2012)

ples mentioned in this paper are available also on the web page »Songs of the European singing cicadas« <<http://www.cicadasong.eu/>>.

Results

Distribution

Faunistic data from the Greek island of Crete (Kriti) are presented in Table 1 and Fig. 2. All recordings, observations and collections were made by the authors.

Description of the calling song pattern

We made many recordings and also collected six males that were previously recorded. We analysed 21 recordings (18. 8. 2005: Aghios Nikolaos, Kritsa – 2 recordings; 29. 5. 2006: Adele, Pigi – 11 recordings; 1. 6. 2006: Neapoli, Drasi – 8 recordings).

In all localities, we detected males producing the same song pattern, which is most probably the calling song. We did not record or hear any other song pattern and did not observe any wing movements during the song production.

The CALLING SONG of *P. aschei* consists of two patterns: (i) a monotonous repetition of short echemes (SE) and, (ii) a continuous buzzing sound, which form three phrases (Figs. 3, 4, 5). Phrase A (PhrA) consists of SE. Phrase B (PhrB) has an introductory part with a continuous sound or long echeme (LE) that switches without any

interruption to a series of SE. The phrase C (PhrC) consists of a continuous song with characteristic modulation of song intensity.

TIME PARAMETERS. The calling song consists of a series of phrases, together forming a complete calling song with typical duration of many minutes (Fig. 3). The shortest song lasted 8.3 s and the longest one 3 min 42 s. Altogether we measured 26 min 17 s of recordings.

During the recording and listening in the field we at first assumed that the song starts with PhrA followed by PhrB and PhrC. In analysed recordings we found 133 repetitions of 15 combinations of phrases with the assumption that the song sequence starts with PhrA. Most often the combination AC was used, which was repeated 31 times (27.4%), followed by ACC (15 times, 13.3%), AAC (7, 6.2%), ABC (7, 6.2%), AABC (5, 4.4%), AABBC (4, 3.5%), ABBC (4, 3.5%), AB (3, 2.7%) and ACCC (3, 2.7%). All other 29 combinations were repeated only twice or once.

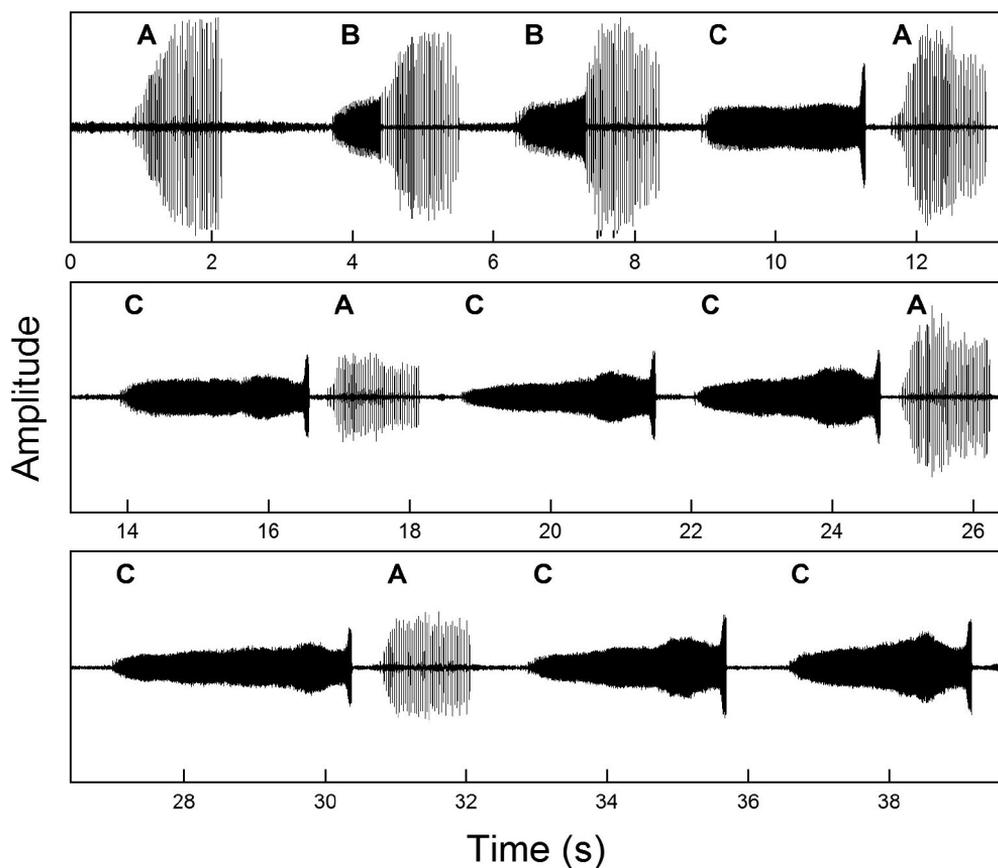


Fig. 3: Oscillogram of the calling song of *Pagiphora aschei*. A – phrase A, B – Phrase B, C – phrase C.

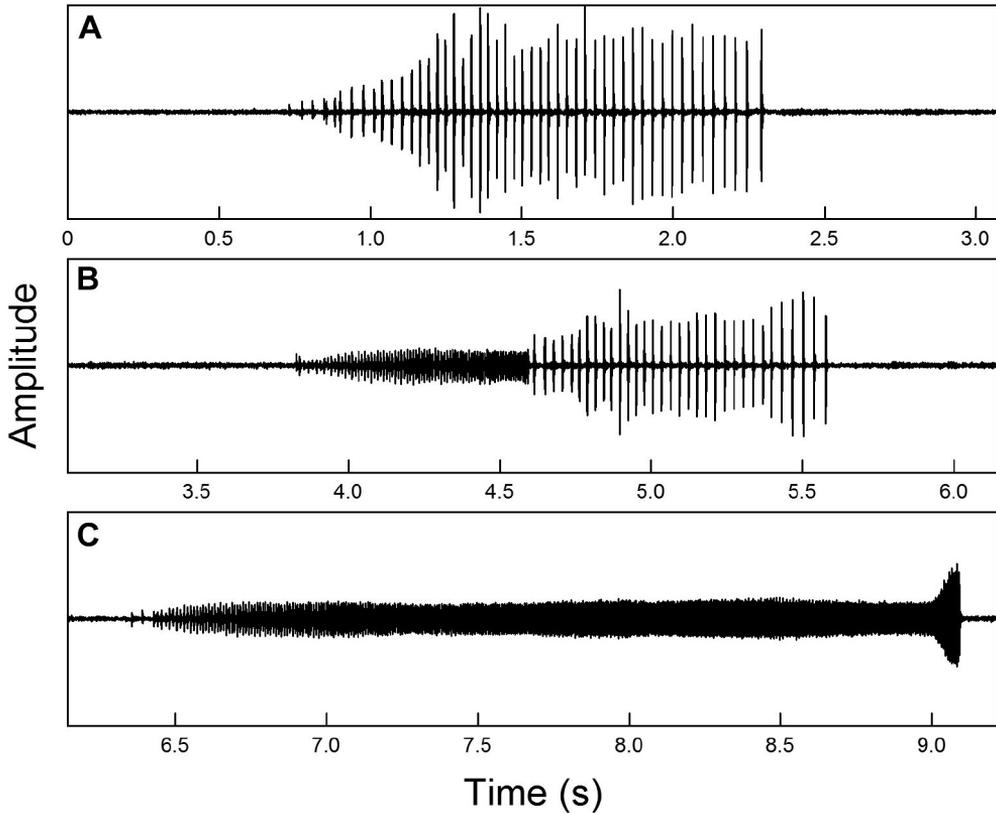


Fig. 4: Oscillogram of the calling song of *Pagiphora aschei*. A – phrase A, B – Phrase B, C – phrase C.

Duration of PhrA is 1.24 ± 0.19 s and consists of 29 to 52 SE, with repetition rate of 32.2 ± 2.9 echemes per second. The duration of SE is 7.76 ± 1.49 ms with the interval between echemes being 23.45 ± 4.48 ms (Table 2, Figs. 4 and 5).

PhrB is 1.64 ± 0.35 s long. The LE lasts 0.49 ± 0.28 s and represents 10-49% of the whole PhrB duration. The duration of the last part with series of SE is 1.17 ± 0.17 s and consists of 30 to 45 echemes, with a repetition rate of 31.2 ± 1.6 echemes per second. The duration of SE is 9.64 ± 2.27 ms with the interval between echemes 22.11 ± 3.93 ms (Table 2, Figs. 4 and 5).

PhrC is characterized by continuous buzzing sound. This buzz has characteristic amplitude envelope and increases first slowly in intensity, stabilises in the middle, rises rapidly in intensity at the end and stops abruptly thereafter. PhrC lasts 2.31 ± 0.56 s in total and the last increase in intensity buzz is 0.089 ± 0.016 s long (Table 2, Figs. 4 and 5).

At only one locality (Adele, Pigi; 29. 5. 2006; 11 recordings) we first heard and then recorded a variant of longer PhrC with duration of 3.69 ± 1.03 s and two intensity

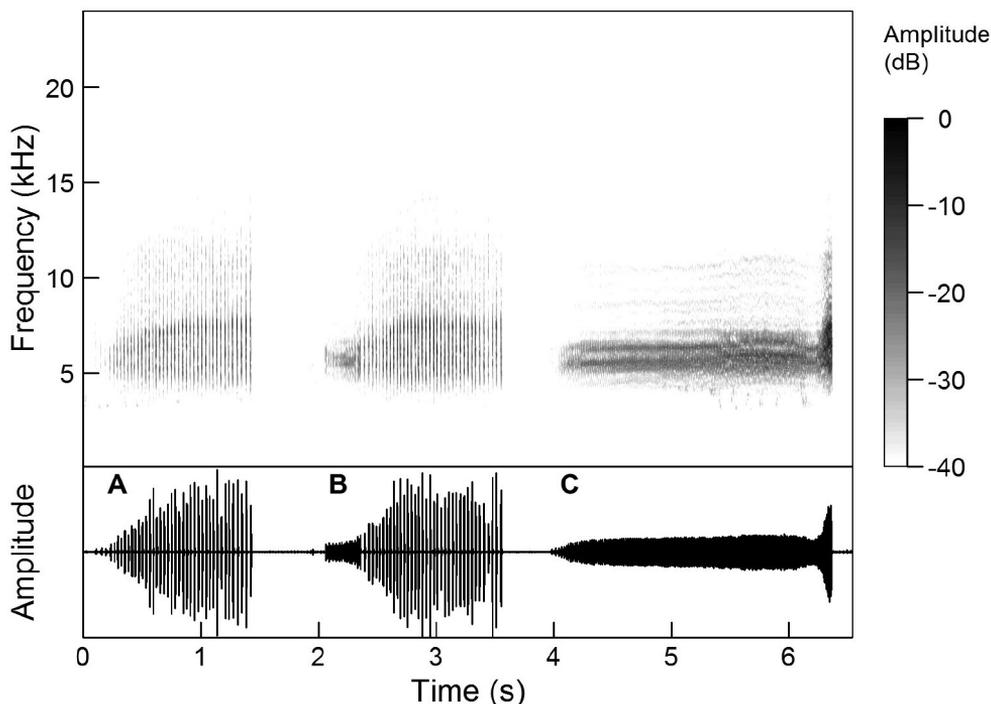


Fig. 5: Spectrogram and oscillogram (below) of the calling song of *Pagiphora aschei*. A – phrase A, B – Phrase B, C – phrase C. (Frequency analysis parameters: Hamming window, overlap = 50%, window length for the analysis = 512).

peaks, one at the second third of duration and one at the end (Table 2, Fig. 6). We never heard or recorded both variants of PhrC sung by the same individual and we never heard or recorded the longer variant with two intensity peaks of PhrC at any other locality.

The interval between phrases was in average 1.3 ± 0.79 s. Sometimes there is longer interval between phrases (5.45 ± 2.62 s), which is possible to interpret as interval between different songs (or song sequences).

The FREQUENCY SPECTRUM of *P. aschei* calling song has a wide range from 4 to 15 kHz. The main peak of frequencies is between 5.2 and 7.3 kHz (6.2 ± 0.5 kHz) with a secondary peak or plateau in the range of 7.5 and 11.4 kHz. The -10 dB range of the main peak covers the frequencies between 4.4 and 8.2 kHz and -20 dB range between 4.1 and 8.7 kHz (Table 2, Figs. 5 and 6).

ECOLOGY AND BEHAVIOUR. We found *P. aschei* in localities from the seacoast to 600 m a.s.l. The adults are on the wings from May to August (our earliest record May, 27th and the latest August, 21st – Table 1). Males usually sat and sang on shrubs or small trees either in macchia or olive tree plantations. Males were active at daytime from sun-

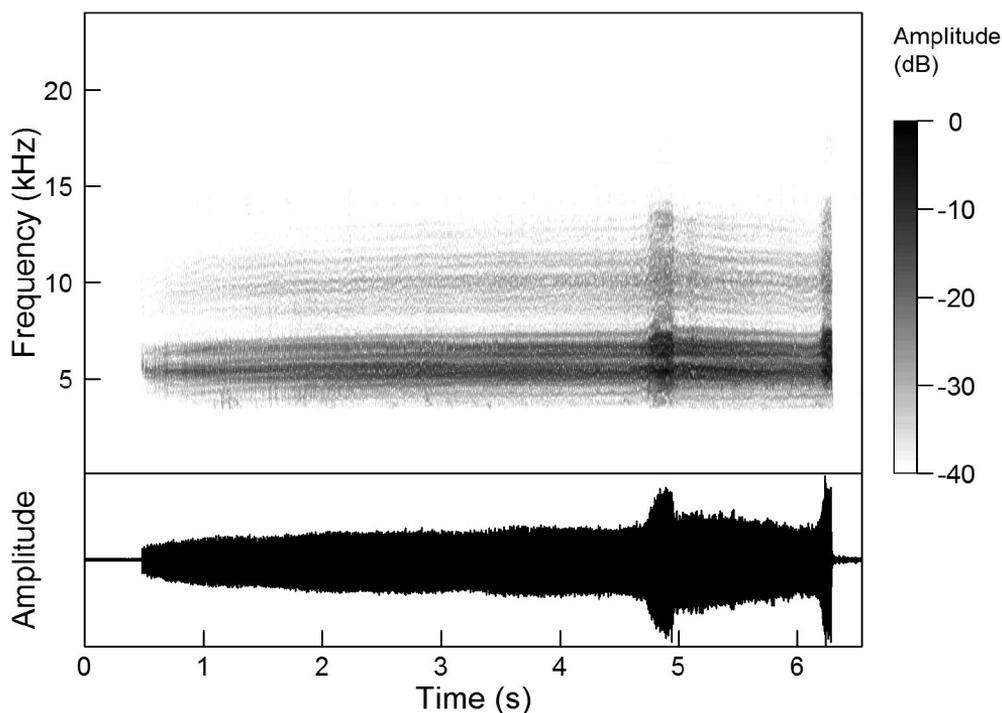


Fig. 6: *Pagiphora aschei*, spectrogram and oscillogram (below) of a variant of the phrase C of the calling song recorded at Adele, Pigi on 29. 5. 2006 (Frequency analysis parameters: Hamming window, overlap = 50%, window length for the analysis = 512).

rise to sunset. A single male can sing at a single spot for very long time (some minutes). When disturbed, male usually stopped singing and remained sitting at the singing position, than flew away.

Discussion

The cicada genus *Pagiphora* Horváth 1912 consists of five species: *P. annulata* (Brullé 1832) distributed in South-East Europe and Asia Minor, *P. aschei* Kartal 1978 from Crete and Antalya, *P. yanni* Boulard 1992 from Anatolia, *P. hauptosa* Boulard 1981 from Asia Minor and *P. maghrebensis* Boulard 1981 from North Africa (Boulard 1981a, 1981b, 1992; Kartal 1978). According to Boulard (1992) *P. yanni* and *P. maghrebensis* are closely related to the Cretan and Antalyan species *P. aschei*, and are less close to *P. annulata* and *P. hauptosa*.

Acoustic signals of *P. yanni* were described by Boulard (1992) and of *P. annulata* by Gogala & Trilar (2000, 2003). According to our knowledge the songs of *P. maghrebensis* and *P. hauptosa* were not investigated yet.

Like in *P. aschei*, the calling song of *P. yanni* consists of a monotonous repetition of short echemes and continuous song and it forms two phrases (Boulard 1992). The first phrase of *P. yanni* is very similar to the phrase B of *P. aschei*, and the second phrase of *P. yanni* to the phrase C of *P. aschei*. Both phrases of *P. yanni* have in intervals a few irregular tymbal clicks that are not present in *P. aschei*.

We measured the temporal parameters of *P. yanni* on a single recording published by Boulard (2006). First phrase is 1.2 ± 0.08 s long (N=7, min=1.11 s, max=1.31 s). The LE at the beginning of the phrase lasts 0.71 ± 0.07 s (N=7, min=0.62 s, max=0.83 s), while the duration of the last part with series of SE is 0.49 ± 0.03 s (N=7, min=0.46 s, max=0.53 s) and consists of 13 to 15 short echemes, which are 7 to 9 ms long. The main peak of frequency of LE is between 6.2 and 6.6 kHz (N=10), while the -10 dB range of the main peak covers the frequencies between 4.9 and 7.3 kHz and -20 dB range between 4.2 and 7.9 kHz. The main peak of frequency of series of SE is between 6.9 and 7.1 kHz (N=10). The -10 dB range of the main peak covers the frequencies between 4.5 and 7.6 kHz and -20 dB range between 4.1 and 8.1 kHz.

Second phrase of *P. yanni* starts with 4 to 7 irregular SE at the end of the preceding interval followed by a continuous buzzing sound, which lasts 0.94 ± 0.16 s (N=7, min=0.73 s, max=1.15 s). This buzz increases first slowly in intensity, stabilises in the middle, rises rapidly in intensity at the end and stops abruptly thereafter. The main peak of frequency is between 5.9 and 6.5 kHz (N=8). The -10 dB range of the main peak covers the frequencies between 5.1 and 7.3 kHz and -20 dB range between 4.6 and 7.7 kHz.

Pagiphora annulata produces calling song with 2.1 to 2.9 s long phrases, composing of 7 to 10 short echemes, which duration and intensity increase toward the end of a phrase. Repetition rate of echemes in a phrase is 3 ± 0.5 echemes per second (Hz). The frequency band is from 2.5 to 6 kHz (-20 dB range) with the peak around 3.9 kHz. In the last part of the calling song of *P. annulata* appear in addition to the tymbal echemes also the clicks of broad frequency range, which are associated with the movement of the wings (Gogala & Trilar 2000). Gogala & Trilar (2003) have shown after analysis with HS video recordings that the additional clicks with broad frequency range appear only in connection with wing flapping. During the parts of song produced purely by tymbal the wings remain in a closed position (Gogala & Trilar 2003). The wing flapping is observed also in *P. yanni* during the courtship song with male and female at short distance, but it produces, according to Boulard (1992), a barely audible noise for human ear. In *P. aschei* we did not detect any wing movements during the song production, nor recorded or heard broad band signals of wing flaps.

According to our acoustic comparison we can also say that the song of *P. aschei* is more similar to the song of *P. yanni* and differs in many ways to the sound emission of *P. annulata*.

The calling songs of these species mainly differ in their temporal pattern but not radically in their frequency properties. Gogala & Trilar (2003) report for tymbal parts of the song of *P. annulata* the main energy at frequencies between 2.4 and 6 kHz (peak

at 3.9 kHz). The main energy for *P. yanni* is at frequencies between 4.1 and 8.1 kHz (peak 5.9-7.1 kHz), while for *P. aschei* is between 4.1 and 8.7 kHz (peak 5.2-7.3 kHz). This frequency homogeneity can be related to their morphological similarity.

Bennet-Clark & Young (1994) predict that abdominal cavity and tympana act as the components of the Helmholtz resonator that is excited by the drive from tymbals and inferred a simple equation where the size of the body and frequency of sound emitted are usually negatively correlated. According to this prediction the emitted frequency peak of such small cicada (body length range 15-17 mm) should be around 12 kHz (Gogala & Trilar 2000, Gogala et al. 2005). However, this is valid for i.e. *Cicadivetta tibialis* (Panzer, 1798) (12-14 kHz) (Gogala et al. 1996), *Cicadivetta flaveola* (Brullé, 1832) (13.5-16 kHz) (Gogala & Drosopoulos 2006), *Cicadetta mediterranea* Fieber 1876 (12-15 kHz) (Gogala & Popov 1997). As mentioned above in all *Pagiphora* species investigated so far the frequency properties are at least half lower. This is most probably due to different anatomy either of tympana, tymbals or abdomen. To find out the proper reason for this phenomenon further investigations are needed.

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Table 1. Faunistic data for *Pagiphora aschei* from the Greek island of Crete. All recordings, observations and collections were made by the authors.

| | | | | |
|--|---------------------------------|-------|-----------------------------|------------------------------------|
| Hanya: Granvousa, Balos | 35°35'8.4" N, 23°35'31.5" E | 10 m | 17. 8. 2006 | collected (1♂) and photographed |
| Hanya: Kissamos, Drapanias | 35°29'38.7" N, 23°41'42.4" E | 30 m | 18. 8. 2006 | exuvia 6 exuvia col- lected |
| Hanya: Kissamos, Nopigia | 35°29'53.3" N, 23°42'0.2" E | 15 m | 15. 8. 2006 | collect6 collected (3♂1♀) |
| Hanya: Kissamos, Potamida | 35°28'15.8" N, 23°41'48.2" E | 40 m | 14. 8. 2006 | song heard |
| Hanya: Kissamos, Voulgaro | 35°27'15.2" N, 23°41'41.3" E | 340 m | 10. 8. 2006 | song heard |
| Hanya: Kissamos | 35°29'37.6" N, 23°39'17.5" E | 10 m | 10. 8. 2006 | song heard |
| Iraklio: Iraklio, Amoudara | 35°20'15.1" N, 25°04'43.7" E | 5 m | 2. 6. 2006 | song heard |
| Iraklio: Iraklio, Knossos | 35°17'51.4" N, 25°09'40.4" E | 250 m | 3. 6. 2006 | song heard |
| Lasithi: Aghios Nikolaos, Ellounda | 35°15'27.0" N, 25°43'37.8" E | 24 m | 31. 5. 2006 | collected (2♂) |
| Lasithi: Aghios Nikolaos, Kritsa | 35° 9'56.4" N, 25°39'18.4" E | 300 m | 14. and 18. 8. 2005 | recorded |
| Lasithi: Aghios Nikolaos, Kritsa, Panaghia Kera | 35°09'23.9" N, 25°39'19.2" E | 225 m | 2. 6. 2006 | song heard |
| Lasithi: Aghios Nikolaos, Kritsa, below the peak Lato | 35°10'10.8" N, 25°39'21.7" E | 315 m | 31. 5. 2006 | recorded |
| Lasithi: Aghios Nikolaos, Kritsa, Lato | 35°10'23.3" N, 25°39'13.9" E | 313 m | 2. 6. 2006 | song heard |
| Lasithi: Neapoli, Drasi | 35°13'16.1" N, 25°36'17.3" E | 340 m | 1. 6. 2006 | recorded |
| Rethymno: Adele, Adelianos Kambos, hotel Adele Mare | 35°22'17.7" N, 24°33'04.9" E | 2 m | 28. 5. 2006 | song heard |
| Rethymno: Adele, Loutra | 35°21'11.7" N, 24°35'9.84" E | 100 m | 29. 5. 2006 | song heard |
| Rethymno: Adele, Mesi | 35°20'16.2" N, 24°34'31.7" E | 210 m | 27. 5. 2006 | recorded |
| Rethymno: Adele, Pigi | 35°21'30.4" N, 24°35'57.5" E | 41 m | 29. 5. 2006 | recorded |
| Rethymno: Armeni, Latet Minoan Cementery | 35°18'55.8" N, 24°27'58.1" E | 355 m | 28. 5. 2006 | recorded |
| Rethymno: Platanias | 35°22'5.6" N, 24°31'34.4" E | 10 m | 10., 15. and 21. 8. 2003 | collected (4♂) and photographed |
| Rethymno: Platanias | 35°21'54.0" N, 24°31'2.1" E | 458 m | 30. 5. 2006 | collected |
| Rethymno: Spili | 35°13'12.8" N, 24°32'03.0" E | 470 m | 28. 5. 2006 | song heard |

Table 2. Temporal parameters of the calling song of *Pagiphora aschei*. N – number of SE; N/s – number of SE per second; LE/sSE – ratio between duration of LE and series of SE; **PhrA – phrase A**; PhrA Dur – duration of phrase A; PhrA SE No – number of short echemes (SE) in phrase A; PhrA SE Rep Rate – repetition rate of SE in phrase A; PhrA SE Dur – duration of SE in phrase A; PhrA SE Int – duration of interval between SE in phrase A; PhrA CarFrMax – carrier frequency maximum of phrase A; **PhrB – phrase B**; PhrB Dur – duration of phrase B; PhrB LE Dur – duration of long echeme (LE) of phrase B; PhrB sSE Dur – duration of series of SE in phrase B; PhrB SE No – number of SE in phrase B; PhrB SE Rep Rate – repetition rate of SE in phrase B; PhrB SE Dur – duration of SE in phrase B; PhrB SE Int – duration of interval between SE in phrase B; PhrB LE CarFrMax – carrier frequency maximum of LE of phrase B; PhrB sSE CarFrMax – carrier frequency maximum of series of SE in phrase B; **PhrC – phrase C**; PhrC Dur – duration of phrase C; PhrC CarFrMax – carrier frequency maximum of phrase C; Phr Int – duration of interval between phrases; Phr Int Long – duration of longer intervals, which can be interpreted as interval between different songs or song sequences.

| Phrase | Parameter | Unit | Count | Mean | St. Dev | Min | Max |
|--------|-------------------|------|-------|-------|---------|-------|-------|
| A | PhrA Dur | s | 204 | 1.24 | 0.19 | 0.84 | 1.69 |
| A | PhrA SE No | N | 95 | 40.4 | 4.7 | 29 | 52 |
| A | PhrA SE Rep Rate | N/s | 96 | 32.2 | 2.9 | 23.3 | 29.1 |
| A | PhrA SE Dur | ms | 3534 | 7.76 | 1.49 | 6.26 | 12.54 |
| A | PhrA SE Int | ms | 3585 | 23.45 | 4.48 | 14.6 | 35.54 |
| B | PhrB Dur | s | 106 | 1.64 | 0.35 | 0.90 | 2.40 |
| B | PhrB LE Dur | s | 104 | 0.49 | 0.28 | 0.12 | 1.24 |
| B | PhrB sSE Dur | s | 104 | 1.17 | 0.17 | 0.76 | 1.50 |
| B | LE/sSE | % | 101 | 28.20 | 10.93 | 10.05 | 49.29 |
| B | PhrB SE No | N | 23 | 38.5 | 3.8 | 30 | 45 |
| B | PhrB SE Rep Rate | N/s | 20 | 31.18 | 1.59 | 29.48 | 35.68 |
| B | PhrB SE Dur | | 784 | 9.64 | 2.27 | 2.09 | 14.63 |
| B | PhrB SE Int | | 723 | 22.11 | 3.93 | 14.61 | 29.27 |
| B | PhrB LE CarFrMax | kHz | 15 | 5.68 | 0.33 | 5.25 | 6.19 |
| B | PhrB sSE CarFrMax | kHz | 23 | 6.63 | 0.59 | 5.25 | 7.31 |
| C | PhrC Dur | s | 143 | 2.66 | 0.93 | 1.12 | 5.55 |
| C | PhrC Dur 1vrh | s | 75 | 2,31 | 0,56 | 0,75 | 3,40 |
| C | PhrC Dur 2vrha | s | 46 | 3,69 | 1,03 | 1,82 | 5,81 |
| C | PhrC CarFrMax | kHz | 97 | 6.39 | 0.56 | 5.44 | 7.31 |
| | Phr Int | | 397 | 1.30 | 0.79 | 0.18 | 3.15 |
| | Phr Int Long | | 54 | 5.45 | 2.62 | 3.23 | 16.55 |

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