Cicada cretensis sp. n. (Hemiptera, Cicadidae) from southern Greece

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Abstract: Based on material collected recently on the island of Crete, in southern Greece, the present study describes a new species of the genus *Cicada*. The new species is closely related to both *C. orni* and *C. mordoganensis*, but can be distinguished from these by characters of the male genitalia and the distinctive calling song, which is illustrated by oscillograms, sonagrams and amplitude spectra. Comparison of the calling song of *C. cretensis* sp. n. with those of *C. orni* and *C. mordoganensis* showed considerable differences, especially in the inter-echeme interval, which is in general shorter in the new species than in either *C. orni* or *C. mordoganensis*. Moreover, the duration of the echemes of *C. cretensis* sp. n. is, on average, considerably longer than in *C. orni* and shorter than in *C. mordoganensis*.

Key words: Hemiptera, *Cicada,* taxonomy, calling song, new species, Greece, Crete.

Introduction

The genus *Cicada* L., 1758 is distributed mainly in the Mediterranean area and includes the following six species: *Cicada barbara* Stål, 1866*, C. cerisyi* Guérin-Méneville, 1844*, C. lodosi* Boulard, 1979*, C. mordoganensis* Boulard, 1979*, C. orni* L., 1758 and *C. permagna* Haupt, 1917. Several other species were described from Italy in the past, but these are either synonyms of *C. orni* (e.g., *C. oleae* Costa, 1877) or belong to different taxa (e.g., *C. afona* Costa, 1834 now within the Cercopidae) (Servadei, 1969; Nast, 1972)

Cicada barbara is known to occur in the SW part of Europe and N Africa (Algeria, Italy, Libya, Portugal, Sardinia, Sicily, Spain and Tunisia) (Nast, 1972; Boulard, 1981; Quartau & Fonseca, 1988; Boulard, 1995), *C. cerisyi* is only found in Egypt and Libya (Nast, 1972; Schedl, 1993). On the other hand, *C. lodosi* and *C. permagna* seem to occur in Turkey only, in the eastern part of the Mediterranean area (Nast, 1972; Boulard, 1979; Lodos & Kalkandelen, 1981; Boulard, 1995). *Cicada mordoganensis* is also an eastern species described from Turkey, but it can be also found in several Greek islands along the Turkish coast (Boulard, 1979; Lodos & Kalkandelen, 1981; Simões et al., 2000). *Cicada orni* is the species with the widest distribution from the Iberian peninsula to W Greece and Turkey (Quartau et al., 1999) and some countries in the near East (Nast, 1972), and also around the Black Sea (Popov, 1975).

This study presents the description of a new species of the genus *Cicada* collected in S Greece, *C. cretensis* sp. n. Field-work has been conducted on the Greek and Turkish mainlands and on numerous Aegean islands and the new species was found on the island of Crete (Tabs 1, 2). As referred to below, the new species is closely related to both *C. orni* and *C. mordoganensis* but can be distinguished from these by characters of the male genitalia and through the calling song, which is quite different.

Material and methods

Field-work was carried out on the island of Crete during the summer of 2001 (Tab. 1). Altogether, the calling song of 20 males from this island was recorded in the field. The acoustic recordings were made during the warmest hours of the day, usually at temperatures of 30–38 °C with a TCD-D10 ProII digital Sony DAT recorder (frequency range 20–22 000 Hz) connected to a compatible dynamic microphone (frequency range 50–18 000 Hz). At a later stage, specimens were collected by hand or by a sweeping net. Song terminology follows that of Gogala & Trilar (1999, 2000) and Gogala & Popov (2000).

Sound recordings were analysed in the time and frequency domains and were shown as oscillograms, sonagrams and amplitude spectra using a Digital Audio Card (sound card with a sampling rate of 44.1 kHz, and 16 Bit dynamic range) and suitable software (Avisoft-SASLab Pro) as in previous analyses (Quartau et al., 1999, 2000; Simões et al., 2000). In the frequency domain, spectra were computed with a resolution of 512 points of FFT-Length and a Hamming Window.

Table 1. Populations of *Cicada cretensis* sp. n. sampled, with number of specimens taken (*N1*), number of males recorded (*N2*) and date of collecting and recording.

Site	*N1*	*N2*	Date of collecting and recording
Akoúmia (35°10′ N, 24°35′ E)	3 ♂♂; 4 ♀♀	–	10.VII.2001
Chania (35°31′ N, 24°1′ E)	11 ♂♂; 4 ♀♀	2 ♂♂	9.VII.2001
Lerapatra (35°1′ N, 24°45′ E)	1 ♂	2 ♂♂	11.VII.2001
Omalos (35°20′ N, 23°54′ E)	–	1 ♂	9.VII.2001
Pilalimata (35°2′ N, 25°59′ E)	3 ♂♂; 3 ♀♀	–	11.VII.2001
Pirgos (35°0′ N, 25°9′ E)	11 ♂♂; 2 ♀♀	2 ♂♂	10.VII.2001
Spili (35°13′ N, 24°32′ E)	–	4 ♂♂	10.VII.2001
Tylissos (35°18′ N, 25°1′ E)	14 ♂♂; 7 ♀♀	3 ♂♂	8.VII.2001
Vai (35°16′ N, 26°16′ E)	–	6 ♂♂	11.VII.2001
Total	43 ♂♂; 19 ♀♀	20 ♂♂	

Table 2. Populations of *Cicada mordoganensis* and *C. orni* sampled with number of males recorded for sound analyses (*N*) and dates of recording.

Populations	Area	Species	*N*	Dates of recording
Chios (Greece) (38°31′ N, 26°2′ E)	Island	*C. mordoganensis*	14	10.VII.1999; 6–8.VII.2000
Ikaria (Greece) (37°36′ N, 26°11′ E)	Island	*C. mordoganensis*	9	1–10.VII.1998; 8–9.VII.1999
Koz (Greece) (36°48′ N, 27°4′ E)	Island	*C. mordoganensis*	13	11–12.VII.2000
Rhodes (Greece) (36°11′ N, 27°56′ E)	Island	*C. mordoganensis*	3	8.VII.2000
Samos (Greece) (37°45′ N, 26°49′ E)	Island	*C. mordoganensis*	17	12–14.VII.1997; 13.VII.1998
Turkish south coast (several sites: Lat. from 36°56′ N to 39°17′ N, Long. from 26°46′ E to 28°37′ E)	Mainland	*C. mordoganensis*	14	21–23.VI.2003
Turkish west coast (several sites: Lat. from 36°49′ N to 36°58′ N, Long. from 29°10′ E to 34°40′ E)	Mainland	*C. mordoganensis*	14	23–24.VI.2003
Total			84	
Andros (Greece) (37°55′ N, 24°48′ E)	Island	*C. orni*	3	3–4.VII.1999
Lesbos (Greece) (39°11′ N, 26°2′ E)	Island	*C. orni*	3	13.VII.2000
Naxus (Greece) (37°6′ N, 25°28′ E)	Island	*C. orni*	4	6.VII.1999
Skyros (Greece) (38°54′ N, 24°32′ E)	Island	*C. orni*	17	28.VI.2002
Assos (Turkey) (39°36′ N, 26°27′ E)	Mainland	*C. orni*	1	27.VI.2003
Athens (Greece) (37°58′ N, 23°43′ E)	Mainland	*C. orni*	19	9–10.VII.1997; 15.VII.1998; 13.VII.1999
Evia (Greece) (38°27′ N, 24°4′ E)	Mainland	*C. orni*	12	29.VI.2002
Itea (Athika, Greece) (38°26′ N, 22°25′ E)	Mainland	*C. orni*	24	26 and 29.VI.2002
Kosmas (Greece) (37°6′ N, 22°44′ E)	Mainland	*C. orni*	2	24.VI.2002
Neapolis (Greece) (35°31′ N, 24°1′ E)	Mainland	*C. orni*	7	25.VI.2002
Paralio (Greece) (37°15′ N, 22°52′ E)	Mainland	*C. orni*	7	24.VI.2002
Skala (Athika, Greece) (38°40′ N, 23°5′ E)	Mainland	*C. orni*	4	29.VI.2002
Total			103	

For each male, recordings of about one minute were analysed and the following 13 acoustic variables were calculated (Tab. 3): number of echemes/second, echeme duration, inter-echeme interval, echeme period, ratio of echeme to inter-echeme interval, peak frequency, bandwidth (at −20 dB), quartile 25%, quartile 50%, quartile 75%, interquartile range, minimum frequency and maximum frequency.

In order to test interspecific acoustic differentiation between *C. cretensis* sp. n. and the closely related *C. orni* and *C. mordoganensis*, an R-type ordination known as principal component analysis was carried out using all measured acoustic variables and all recorded males of the new species ($n = 20$) and males of *C. orni* ($n = 103$), and *C. mordoganensis* ($n = 84$) from geographically close populations (Tabs 1, 2). Data were standardized. Two-sample comparisons were tested using non-parametric Mann-Whitney (MW) *U* tests at a significance level of $P = 0.05$. Statistical tests were made using Statistica 6.0 software (StatSoft, 2001).

All specimens were measured and males were dissected for examination of the genitalia.

Cicada cretensis sp. n. (Figs 1, 2)

Description. Morphology. The new species looks externally very similar to the closely related *C. orni* and *C. mordoganensis* and can hardly be distinguished from these based on external morphological characters only.

Overall length from apex of crown to tips of the tegmina in rest position alongside the body: males, 40–

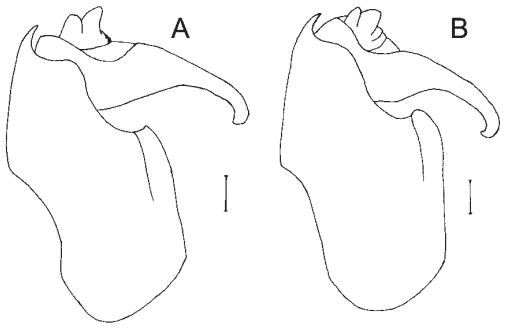

Fig. 1. Lateral view of the pygophore of *Cicada cretensis* sp. n.: A – Holotype, male, Chania 9.VII.2001; B – Paratype, male, Tyllissos 8.VII.2001. Scales 0.05 mm.

Fig. 2. Ventral view of the incision of the seventh abdominal sternite of *Cicada cretensis* sp. n. Allotype, female, Chania 9.VII.2001. Scale 0.05 mm.

47 mm (average 42.5 mm, $n = 29$); females 40–47 mm (average 43.9 mm, $n = 19$). The new species is slightly bigger than *C. orni* (males, 35–43 mm, average 39.4 mm, $n = 38$; females 36–44 mm, average 40 mm, $n = 15$) and about the same size as *C. mordoganensis* (males, 40–47 mm, average 42.7 mm, $n = 30$; females 39–46 mm, average 41.2 mm, $n = 11$).

Male. General colouration from brown to brownish yellow, not as greenish as in *C. orni* and resembling *C. mordoganensis*. Head triangular, spotted with dark brown; eyes brown. Thorax with pronotum distinctly broader and longer than head, brown to olivaceous, with a median longitudinal light brown line; cruciform elevation spotted with dark brown and with the two typical U-shaped spots of light brownish. Legs light brown like other closely related *Cicada* species. Forewings with veins brownish yellow and with two to four brown spots on veins m-cu, m, r-m and r; these spots usually smaller than in *C. mordoganensis* and well defined as is usual in *C. orni*. Hindwings with veins brownish yellow. Abdomen brownish to dark brown, posterior margin of each segment sometimes yellowish. Opercula yellowish and roundish as in closely related species. Male genitalia (Fig. 1) usually differ in structure of pygophore: well developed dorsal beak at tip of dorsal margin is generally longer than in *C. mordoganensis* and more curved than in *C. orni*.

Female. In general, structure and colouration similar to the male. The abdomen is usually darker brown. Incision of seventh abdominal sternite with two small lobes in ventral view (Fig. 2).

Acoustic behaviour. Table 3 gives a summary of each of the time and spectral characteristics of the calling song that were measured for the new species and the closely allied *C. orni* and *C. mordoganensis.* Considering average values, this signal (Fig. 3) can be described in the time domain as having echemes with 0.22 ± 0.04 s of duration that are separated by intervals of 0.10 ± 0.04 s. With respect to the spectral characteristics of the signal, it shows a peak frequency of about 5.36 ± 0.34 kHz, and a bandwidth (-20 dB) of 8.26 ± 0.99 kHz. The mean frequency (quartile 50%) is about 6.12 ± 0.22 kHz and the interquartile range of frequency is relatively small, averaging 2.44 ± 0.29 kHz. The new species can be distinguished acoustically from C. *orni* and C. *mordoganensis* by almost all of the investigated variables.

Table 4 gives the results from a Mann-Whitney U test with the significant differences for each variable when comparing the new species with *C. orni* or *C. mordoganensis*. *Cicada cretensis* sp. n. shows significant differences for almost all studied variables, namely the duration of the echeme and the inter-echeme interval: the duration of the echeme of *C. cretensis* sp. n. is, on average, intermediate between *C. orni* and *C. mordoganensis* and the inter-echeme interval is generally shorter in the new species (Tab. 3).

There are also some differences in the frequency domain. In general, the new species has higher frequencies than *C. mordoganensis*, and to a lesser extent also than *C. orni* (Tab. 3).

Material examined. Holotype – male: Crete, Chania (35°31′ N, 24°1′ E), 9.VII.2001; **Allotype** – female: Crete, Chania (35°31′ N, 24°1′ E), 9.VII.2001; **Paratypes:** 14 ♂♂, 7 ♀♀, Crete, Tylissos (35°18′ N, 25°1′ E), 8.VII.2001; 10 ♂♂, 3 ♀♀, Crete, Chania (35°31′ N, 24°1′ E), 9.VII.2001; 11 ♂♂, 2 ♀♀, Crete, Pirgos (35°0′ N, 25°9′ E), 10.VII.2001; 3 ♂♂, 4 ♀♀, Crete, Akoúmia (35°10′ N, 24°35′ E), 10.VII.2001; 3 ♂♂, 2 ♀♀, Crete, Pilalimata (35°2′ N, 25°59′ E), 10.VII.2001; 1 ♂, Crete, Lerapatra (35°1′ N, 25°45′ E), 11.VII.2001. All specimens collected by P. Simões. Holotype and allotype deposited at the Natural History Museum (Museu Bocage), Lisbon, remaining paratypes in the collection of the first author.

Etymology. The new species is named after the island where it was found, i.e. Crete.

Distribution. The new species seems to be endemic to the island of Crete. It probably evolved during the middle and late Miocene after the geographic isolation of the island of Crete, which was a part of the so called Hellenic arc, from the Aegean landmass in the north (Welter-Schultes, 2000).

Ecological notes. Males sing usually on olive trees (*Olea europaea*), sometimes also on pines (*Pinus halepensis*) and other trees such as *Eucalyptus* and *Cupressus*. Frequently they sing in chorus like *C. mordoga-*

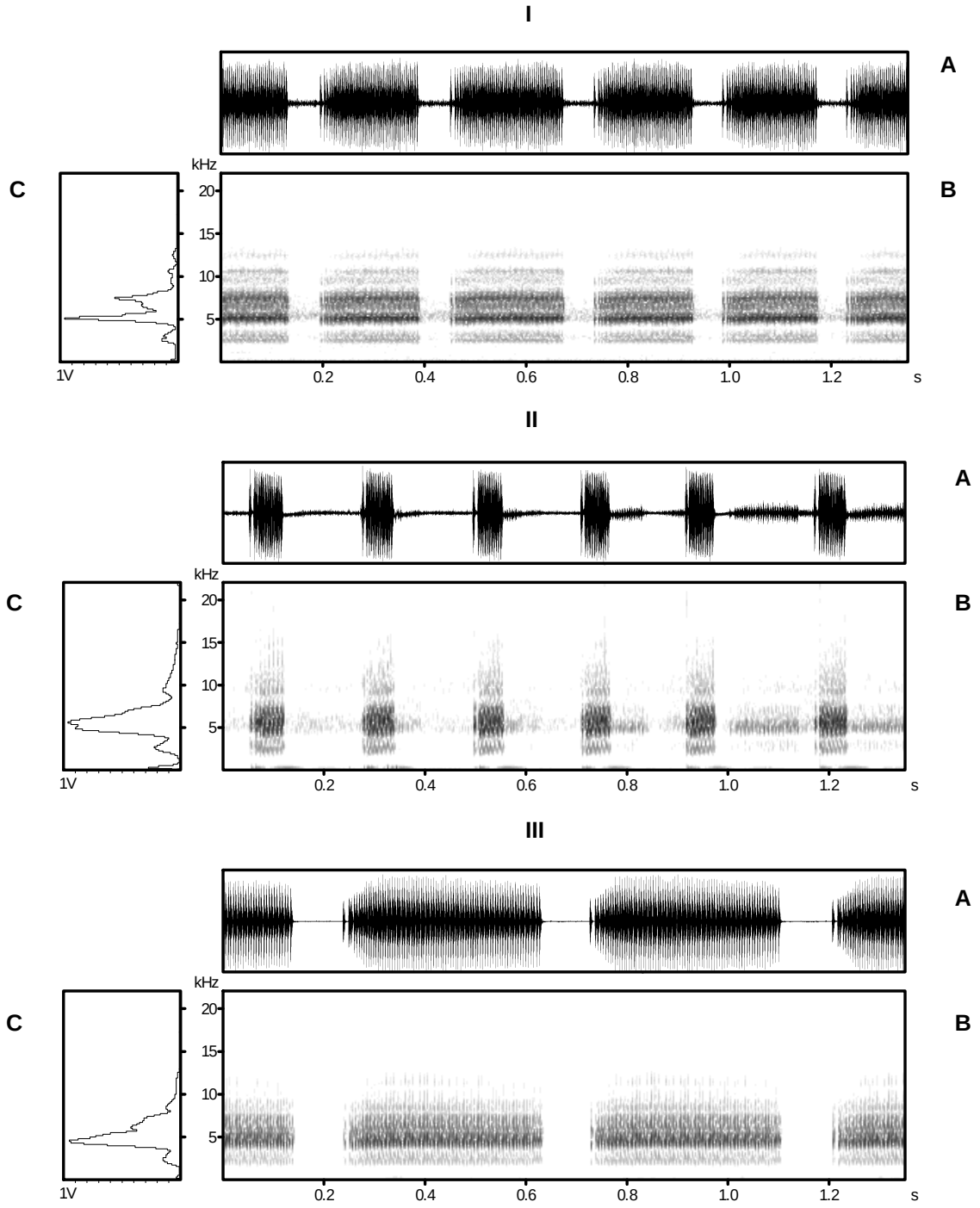

Fig. 3. Acoustic profiles: I – *Cicada cretensis* sp. n., male from Chania; II – *C. orni*, male from Skyros; III – *C. mordoganensis*, male from Samos. A – oscillogram, B – sonagram, C – amplitude spectrum.

nensis and, to a lesser extent, *C. orni*, producing the loud cicada sound so common during the Mediterranean summer. This was the only species belonging to the genus *Cicada* found in Crete.

Differential diagnosis. From the other Mediterranean *Cicada* species *C. cretensis* sp. n. can be easily distinguished by its overall size, the pygophore structure and by the calling song. It is distinctly larger than *C. cerisyi* (cf. Schedl, 1993) and much smaller than both *C. lodosi* and *C. permagna* (cf. Boulard, 1979). The calling song can be easily distinguished from *C. barbara* and *C. lodosi,* since the signal is not continuous as in these two species. The new species is closely related to both *C. orni* and *C. mordoganensis* but can, in general, be separated from these by characters of

Table 3. Descriptive statistics of the 13 acoustic variables investigated in *Cicada cretensis* sp. n. ($n = 20$), *C. orni* ($n = 103$) and *C. mordoganensis* ($n = 84$). The time and frequency characteristics are in seconds and in Hz, respectively.

	C. cretensis sp. n.		*C. orni*		*C. mordoganensis*	
	Average ± SD	Range	Average ± SD	Range	Average ± SD	Range
No. echemes/s	3.25 ± 0.58	2.15–4.45	4.15 ± 1.13	2.23–7.08	2.26 ± 0.29	1.58–3.03
Echeme duration	0.22 ± 0.04	0.16–0.28	0.07 ± 0.02	0.04–0.17	0.32 ± 0.26	0.19–0.49
Inter-echeme interval	0.10 ± 0.04	0.05–0.19	0.19 ± 0.07	0.06–0.35	0.13 ± 0.03	0.08–0.27
Echeme period	0.32 ± 0.06	0.23–0.46	0.26 ± 0.07	0.14–0.45	0.45 ± 0.06	0.33–0.63
Ratio echeme/ inter-ech. interval	2.85 ± 1.18	1.50–6.20	0.52 ± 0.37	0.21–2.48	2.62 ± 0.82	1.20–5.59
Peak frequency	5355.16 ± 335.93	5056.08–6475.40	5015.36 ± 507.28	4061.71–6584.29	4442.31 ± 296.92	3716.35–5106.98
Bandwidth (−20dB)	8256.63 ± 989.90	6969.85–10072.50	7565.95 ± 1400.63	4391.51–11280.30	6175.66 ± 1282.01	3132.40–10355.00
Quartile 25%	5246.04 ± 148.26	4915.00–5605.71	4817.92 ± 359.92	4047.52–5784.14	4450.83 ± 254.49	3781.06–4921.40
Quartile 50%	6116.68 ± 224.68	5595.00–6468.02	5687.44 ± 442.46	4812.96–6640.51	5070.65 ± 296.71	4376.00–5645.86
Quartile 75%	7683.55 ± 357.85	6949.40–8247.50	7211.54 ± 849.99	5597.78–9948.06	6472.28 ± 576.17	5360.59–7739.29
Quartile 75% – quartile 25%	2437.51 ± 285.57	1656.00–2900.91	2393.62 ± 669.89	1257.78–5205.60	2021.45 ± 488.77	960.33–3792.19
Minimum frequency	2378.96 ± 180.15	1921.89–2758.57	2179.28 ± 289.94	1244.27–3235.48	2238.04 ± 427.44	1441.29–3903.21
Maximum frequency	10640.88 ± 1015.03	9280.46–12596.82	9751.75 ± 1432.80	6966.84–13347.91	8418.66 ± 1163.82	6549.36–12392.86

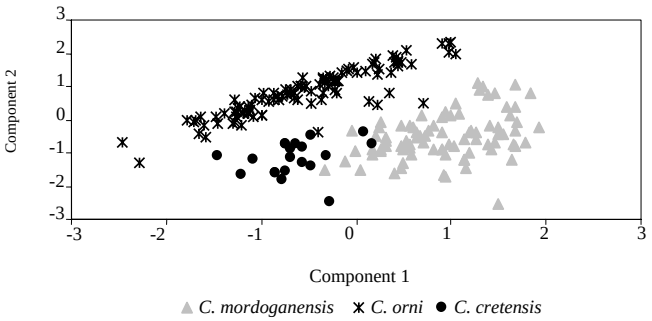

Fig. 4. R-type principal component analysis applied to a total of 207 males (20 of *Cicada cretensis* sp. n., 103 of *C. orni* and 84 of *C. mordoganensis*), based on 13 acoustic variables (standardized data). The first and second axes explain 50.6% and 18.5% of the total variation, respectively.

Table 4. Results of Mann-Whitney *U* tests for the comparisons of *Cicada cretensis* sp. n. ($n = 20$) with *C. orni* or *C. mordoganensis* for each acoustic variable (underlined tests are significant at $P < 0.05$).

Variables	*Cicada cretensis*/ Cicada orni	*Cicada cretensis*/ Cicada mordoganensis
No. echemes/s	0.013999	0.000011
Echeme duration	0.000000	0.000000
Inter-echeme interval	0.000000	0.002232
Echeme period	0.002543	0.000000
Ratio echeme/inter-ech. interval	0.000000	0.552931
Peak frequency	0.018507	0.000001
Bandwidth	0.153361	0.000064
Quartile 25%	0.000224	0.000001
Quartile 50%	0.003251	0.000001
Quartile 75%	0.032223	0.000004
Quartile 75% – quartile 25%	0.395404	0.002366
Minimum frequency	0.008856	0.010104
Maximum frequency	0.062890	0.000034

the pygophore and the calling song: (i) the well defined beak, at the tip of the dorsal margin of the pygophore, is longer in *C. cretensis* sp. n. than in *C. mordoganensis* and more curved than the beak of *C. orni*; and (ii) the inter-echeme interval is shorter in *C. cretensis* sp. n. than in *C. orni* or *C. mordoganensis* and the average duration of the echemes of the new species is longer than in *C. orni* and shorter than in *C. mordoganensis*.

Principal component analysis. Principal component analysis provided useful information on interspecific variation between the new species, *C. orni* and *C. mordoganenis* (Fig. 4). Following the Kaiser criterion, to retain only components with eigenvalues greater than one, four components were extracted and accounting for 90.8% of the total variation (C1 = 50.6%; C2 = 18.5%; C3 = 11.9% and C4 = 9.8%). More than half (69.1%) of the variation in the study was explained by the first two components. There is some separation between the three cicada species analysed when plotting components 1 and 2 (Fig. 4). Specimens of *C. cretensis* sp. n. tended to cluster together and were somewhat separated from *C. orni* and *C. mordoganensis*, giving evidence that it is an independent species. Factor loadings were considerably high for most of the acoustic variables investigated (Tab. 5).

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Table 5. Factor loadings of a principal component analysis based on a correlation matrix between 13 acoustic characters and for a total of 207 specimens: *Cicada cretensis* sp. n. ($n = 20$), *C. orni* ($n = 103$) and *C. mordoganensis* ($n = 84$).

Variables	Comp. 1	Comp. 2	Comp. 3	Comp. 4
No. echemes/s	−0.710810	0.309215	0.065741	−0.594348
Echeme duration	0.719112	−0.671259	0.064371	0.089579
Inter-echeme interval	−0.029552	0.670219	−0.145187	0.686850
Echeme period	0.779575	−0.376417	−0.008134	0.474576
Ratio echeme/inter-ech. interval	0.510107	−0.804714	0.045239	−0.105424
Peak frequency	−0.725862	−0.087961	−0.554169	0.190353
Bandwidth (-20dB)	−0.814888	−0.183626	0.431670	0.226583
Quartile 25%	−0.796918	−0.290778	−0.463628	0.108571
Quartile 50%	−0.910867	−0.197402	−0.192966	0.152209
Quartile 75%	−0.885703	−0.342856	0.133556	0.085984
Quartile 75% – quartile 25%	−0.698619	−0.281982	0.485877	0.047485
Minimum frequency	−0.134085	−0.419332	−0.656705	−0.217668
Maximum frequency	−0.860251	−0.284028	0.286702	0.179785

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