Adres redakcji: Instytut Systematyki i Ewolucji Zwierząt Polskiej Akademii Nauk,
ul. Sławkowska 17, 31-016 Kraków
Address of the Editor: Institute of Systematics and Evolution of Animals,
Polish Academy of Sciences, Sławkowska 17, 31-016 Kraków, Poland

Subscription rate for vol. 44 (year 2001): 55 USD (including postage by surface mail). There is also a possibility to order vertebrate or invertebrate issues only at half price. Supplements (special issues) if any, are extra payed. Single issues will be available at 17.50 USD (including postage).
Payment: the sum should be sent to our Bank Account: Bank Przemysłowo-Handlowy, IV Oddział Kraków, ul. Pijarska 1, 31-015 Kraków, Poland,
Account No.: 10601389-320000468148 (Instytut Systematyki i Ewolucji Zwierząt PAN, Sławkowska 17, 31-016 Kraków, Poland)

ISSN 0065-1710

Cover Design
Jerzy ŚWIECIMSKI

The rhiniceros on the cover presents a nearly complete specimen of the Pleistocene *Coelodonta antiquitatis*, excaved in the layers of ozocerite in Starunia (Eastern Carpathians), 1929. This unique exhibit is shown in the Natural History Museum (Institute of Systematics and Evolution of Animals), Cracow.

Druk i oprawa: Drukarnia Kolejowa Kraków sp. z o.o.
ul. Bosacka 6, 31-505 Kraków
nakład 550 egz. + 25

Acta zool. cracov. 43(3-4): 193-198, Kraków, 22 Dec., 2000

Effect of ambient air temperature on the calling song of *Cicada orni* LINNAEUS, 1758 (Hemiptera: Cicadidae) in Portugal

José Alberto QUARTAU, Sofia SEABRA and Allen SANBORN

Received: 17 April, 2000

Accepted for publication: 30 May, 2000

QUARTAU J. A., SEABRA S., SANBORN A. 2000. Effect of ambient air temperature on the calling song of *Cicada orni* LINNAEUS, 1758 (Hemiptera: Cicadidae) in Portugal. Acta zool. cracov. 43(3-4): 193-198.

Abstract. Calling songs produced by males of *Cicada orni* LINNAEUS, 1758 from the locality of Crato (southern Portugal) were recorded in the field during July of 1999. A temporal song analysis was carried out to investigate the influence of the ambient air temperature on the following parameters: echeme rate, echeme length, interecheme interval and number of pulse units per echeme. A significant correlation was found between the temperature and the interecheme interval. When ambient air temperature rises from 26.5 to 41°C the interecheme interval increases. This relation is not very strong but is statistically significant and confirms previous casual impressions collected in the field by the authors. As a result, the effect of the ambient air temperature on the calling song should be always taken into account when comparing recordings among populations of this cicada or among this and closely related species.

Key words: *Cicada orni*, calling song, ambient temperature, Portugal.

José Alberto QUARTAU, Centro de Biologia Ambiental, Departamento de Zoologia e Antropologia, Faculdade de Ciências de Lisboa, C2, Campo Grande, 1700 Lisboa, Portugal.
e-mail: jquartau@fc.ul.pt
Sofia SEABRA, Centro de Biologia Ambiental, Departamento de Zoologia e Antropologia, Faculdade de Ciências de Lisboa, C2, Campo Grande, 1700 Lisboa, Portugal.
Allen SANBORN – School of Natural and Health Sciences, Barry University, 11300 N.E. Second Avenue, Miami Shores, FL 33161-6695, USA.

I. INTRODUCTION

Males cicadas (Hemiptera: Cicadidae) produce loud airborne sounds using an elaborated tymbal mechanism (CLARIDGE 1985, BENNET-CLARK 1998). Calling songs, which are the most common type of call produced by each species, typically have an important role in pair formation and in species recognition (e.g., CLARIDGE 1985, VILLET 1992).

Sound pulses are created by the action of the large tymbal muscle on the distortion and relaxation of the striated tymbals (SIMMONS & YOUNG 1978; CLARIDGE 1985, BENNET-CLARK 1998). At higher muscle temperatures tymbal muscles contract more rapidly (JOSEPHSON & YOUNG 1979, YOUNG & JOSEPHSON 1983, SANBORN 1997a) and the temporal pattern of the song may be affected by increases in body temperature (JOSEPHSON & YOUNG 1979, SANBORN 1997b).

Environmental factors are certainly important in regulating song production in cicadas, and ambient air temperature is one of the major environmental factors contributing to this regulation (e.g., SANBORN 1997a). Authors in general have noticed that at low temperatures or at low levels of radiant solar energy, no song is produced or the songs of some species of cicadas are produced at a slower rate (e.g., SANBORN & PHILLIPS 1992, SANBORN 1997a; personal observation). Also, studies performed with orthopterans showed that some temporal song parameters are air temperature dependent or influenced by heat radiation (e.g., CICERAN et al. 1994, STIEDL et al. 1994).

Cicada orni LINNAEUS, 1758 is one of the most common and widely distributed cicadas in Portugal, adults being frequently associated with trees, mostly olives (*Olea europaea*) and pines (*Pinus pinaster* and *P. pinea*)(QUARTAU 1995). Adults are active from June to October, the warmest season of the year, and sing mostly during the day. The calling song of this species consist of a repetitive series of separate acoustic elements – the echemes – which are composed of a series of rapid and regularly reproduced amplitude modulated groups of pulses (CLARIDGE et al. 1979, QUARTAU & REBELO 1994, QUARTAU et al. 1999).

A recent study found no significant relationship between temporal song parameters and body temperature in the cicada *Diceroprocta olympusa* (WALKER). Studies investigating the effect of ambient temperature on temporal parameters in cicadas have been contradictory (POPOV 1975, GOGALA et al. 1996, POPOV et al. 1996). Field recordings of a few males of *C. orni* were carried out at different hours of the day and, therefore, at different ambient temperatures, with a view to investigate whether some temporal song parameters of *C. orni* are dependent on the ambient air temperature.

A c k n o w l e d g m e n t s. We are grateful to T. FERNANDES for her assistance in the field and to P. SIMÕES for her help in the acoustic analysis and in the discussion of the results. Support was provided by PRAXIS XXI (project 2/2.1/97/94).

II. MATERIALS AND METHODS

Calling songs of nine males of *C. orni* from Crato (Alto Alentejo, Portugal) were recorded from 1 July to 15 July 1999 (Table I). Each male was recorded in the field for a period of about three minutes and at intervals of one hour over the course of a full day, therefore individuals were recorded at different ambient temperatures. Ambient temperatures in the field ranged from 26.5 to 41°C. A digital Sony DAT recorder connected to a compatible dynamic microphone was used to record the cicada calls. It was possible to obtain multiple recordings from the same individual because in general males tend to remain on the trunk of the same tree for several hours. Air temperatures were taken immediately after each recording. Ambient temperatures were measured at a height of approximately 20 cm in the shade with a maximum and minimum thermometer sensitive to ± 0.5° C.

As known, males of *C. orni* can change the echeme duration and echeme rate of their song in alarm and intraspecific situations (BOULARD 1995; BOULARD & MONDON 1997; personal observation). This has been taken into consideration and all males supposedly involved in inter- and intraspecific interactions were discarded from this study.

As in QUARTAU et al. (1999), song recordings were analysed using the Cool Edit 96 software (Syntrillium Software Corporation) to produce oscillograms (amplitude versus time display). Sampling rate used was of 44,1 kHz. One subsample of about 10 seconds was chosen at random from each recording and the following temporal parameters were measured: echeme rate (number of echemes per second in the sample of 10 seconds), echeme length (duration of each echeme of a sample of 15), interecheme interval (duration of each of the 15 intervals between echemes), and number of pulse units in each echeme of the sample of 15 (Fig. 1). Means and standard deviations for each recording were calculated for the last three parameters. Spearman correlation coefficients were calculated among temperatures and the song parameters as well as among the song parameters investigated.

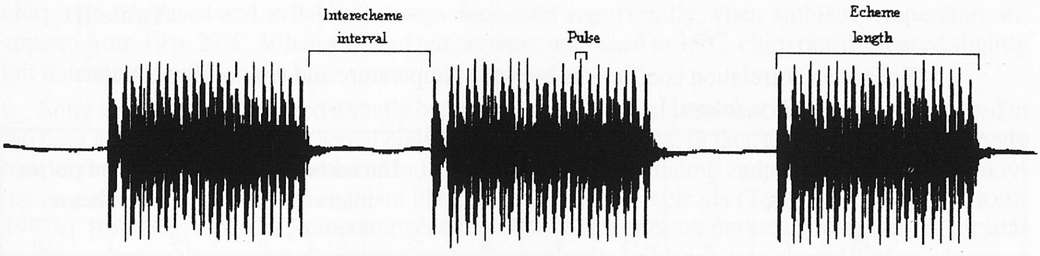

Fig 1. Oscillogram of the calling song of *Cicada orni* L. over a period of about 0.45 seconds: three echemes together; some of the characters measured are shown.

III. RESULTS

Echeme rates calculated for males of *C. orni* varied from 5.63 to 8.18 echemes per second. Echeme length ranged from 0.052 to 0.117 seconds and interecheme intervals from 0.037 to 0.116 seconds. The number of pulse units per echeme varied from 10 to 29. Means and standard deviations of these temporal song parameters for each male with an indication of the range of ambient temperature (and hours of the day) over which recordings were made are given in Table I.

Table I

Mean ± standard deviation of each song temporal parameter for each male of *C. orni* L. and range of hours and temperatures considered; N – number of males

Male	N	Echeme rate (no./s)	Echeme length (s)	Interecheme interval (s)	Number of pulses per echeme	Range of hours	Range of temperaturs (ºC)
699	5	7.75 ± 0.551	0.070 ± 0.0105	0.059 ± 0.0211	17.5 ± 2.63	11:40 – 17:00	36 – 39
700	4	6.39 ± 0.163	0.089 ± 0.0106	0.066 ± 0.0062	21.0 ± 2.37	12:10 – 16:40	36.5 – 39
715	8	7.32 ± 0.708	0.076 ± 0.0154	0.062 ± 0.0099	17.4 ± 2.46	11:35 – 19:00	28 – 35
716	6	6.81 ± 0.383	0.090 ± 0.0111	0.058 ± 0.0095	20.2 ± 2.31	12:20 – 18:40	30 – 34.5
719	7	7.40 ± 0.872	0.091 ± 0.0116	0.042 ± 0.0057	20.7 ± 1.49	11:15 – 18:05	26.5 – 32.5
726	3	7.12 ± 0.216	0.087 ± 0.0262	0.067 ± 0.0068	17.4 ± 0.96	16:30 – 18:25	38.5 – 39
729	7	6.39 ± 0.261	0.085 ± 0.0177	0.074 ± 0.0233	17.9 ± 3.72	9:45 – 17:50	30 – 41
765	7	6.57 ± 0.308	0.081 ± 0.0159	0.070 ± 0.0164	20.1 ± 4.83	11:10 – 18:45	33 – 38
767	4	6.99 ± 0.239	0.065 ± 0.0141	0.080 ± 0.0202	15.8 ± 3.76	10:05 – 13:20	30 – 40.5

The interecheme interval proved to be positively correlated with ambient temperature (Table II). This was corroborated by the casual observation in the field that when ambient temperatures were considerably high (near or over 40ºC), males sang at a slower rythm. The remaining song parameters were not shown to vary significantly with temperature.

Table II

Spearman correlation coefficients between temperature and temporal parameters of the song of *Cicada orni* L. (N=9)

	Echeme rate			Echeme length			Interecheme interval			Number of pulses per echeme		
	rS	*t*	*p*	*rS*	*t*	*p*	*rS*	*t*	*p*	*rS*	*t*	*p*
Temperature	-0.022	-0.15	0.878	-0.248	-1.79	0.079	0.339	2.53	0.015	-0.255	-1.84	0.071

As expected, echeme rate was negatively correlated either with the echeme length or the interecheme intervals. Moreover, echeme length was positively correlated with the number of pulses within each echeme. On the other hand, the interecheme interval was negatively correlated with echeme length as well as with the number of pulses per echeme (Table III).

Table III

Spearman correlation coefficients between song parameters of *C. orni* L. (N=51); $^*p<0.05$

	Echeme rate	Echeme duration	Interecheme interval duration
Echeme length	-0.308*		
Interecheme interval	-0.428*	-0.602*	
Number of pulses per echeme	-0.190	0.875*	-0.700*

IV. DISCUSSION

Males of *C. orni* appeared to sing only when the ambient temperature was higher than 26ºC. On the other hand, their singing activity appeared to be inhibited when strong wind prevailed. These results are similar to environmental conditions limiting *C. orni* calling activity described by CLOUDSLEY-THOMPSON (1960) and CLOUDSLEY-THOMPSON & SANKEY (1957).

The main results of this study indicate that the temporal pattern of the calling song of *C. orni* is temperature dependent, namely in the interecheme interval. Interecheme interval increased with rising ambient air temperature from 26.5 to 41ºC. This effect was not very accentuated but was statistically significant, confirming previous casual impressions during field work. This suggests that the acoustic activity is slowed down with considerably high temperatures (near or higher than 40ºC). This may be an adaptation to allow calling activity at elevated temperatures since elevated body temperatures have been shown to inhibit calling (HEATH & WILKIN 1970) and tymbal muscle activity can elevate body temperature (JOSEPHSON & YOUNG 1979). This pattern of slowing call rate in *C. orni* also contrasts some North American species, such as *Diceroprocta viridifascia* (WALKER), where the number of echemes per unit time increases considerably as ambient (and presumably body) temperature increases (personal observation).

Studies performed in crickets indicate that pulse rates increase with increasing temperature but the temperatures considered on those studies do not reach such high levels as here (CICERAN et al. 1994, WALKER 1998). In a study performed in the laboratory with Orthoptera (STIEDL et al. 1994), chirp rate increased and syllable duration decreased significantly when ambient temperature increased from 19 to 27°C. When ambient temperature increased to 35°C, chirp rate decreased slightly but not significantly.

Song structure is influenced directly by body temperature, and ambient temperature measured in the field may not represent the actual body temperature of cicadas. In fact, cicadas can regulate body temperature by altering the uptake of radiant solar energy, producing endogenous heat, or employing an evaporative cooling mechanism like the Sonoran Desert cicada (TOOLSON 1987, SANBORN 1997a). However, ambient temperature can have some influence on the acoustic activity of cicadas as shown here and, as a result, it is important to take this influence into consideration whenever comparisons are made among the calling songs of different populations of *C. orni*. Moreover, close species such as the sibling *C. mordoganensis* BOULARD, 1979 should be also investigated in order to see whether ambient temperature can mask some of the temporal parameters which are typically used to discriminate between this pair of closely related species. Finally, further studies should include larger samples than those here considered in order to obtain a regression equation which would permit, in part at least, the adjustment of the song measurements of any specimen to a given temperature.

REFERENCES

BENNET-CLARK H. C. 1998. How cicadas make their noise. Scientific American, **May:** 36-39.

BOULARD M. 1995. Postures de cymbalisation, cymbalisations et cartes d'identité acoustique de cigales. 1. Généralités et espéces méditerranéennes (Homoptera, Cicadoidea). EPHE, Biologie et Évolution des Insectes, **7/8** (1994/1995): 1-72.

BOULARD M, MONDON B. 1997. Vies & mémoires de cigales. L' imagier, Équinoxe.

CICERAN M., MURRAY A. M., ROWELL G. 1994. Natural variation in the temporal patterning of calling song structure in the field cricket *Gryllus pennsylvanicus*: effects of temperature, age, mass, time of day, and nearest neighbour. Can. J. Zool., **72**(1): 38-42.

CLARIDGE M. F. 1985. Acoustic signals in the Homoptera: behavior, taxonomy, and evolution. Annu. Rev. Ent., **30**: 297-317.

CLARIDGE M. F., WILSON M. R., SINGHRAO J. S. 1979. The songs and calling sites of two European cicadas. Ecol. Ent., **4**: 225-229.

CLOUDSLEY-THOMPSON J. L. 1960. Some aspects of the fauna of the coastal dunes of the Bay of Biscay. Entomologist's Month. Mag., **96**: 49-53.

CLOUDSLEY-THOMPSON J. L., SANKEY J. H. P. 1957. Some aspects of the fauna of the district around the Étang de Berre, Bouches-Du-Rhone, France. Ann. Mag. Nat. Hist., (12)**10**: 417-424.

GOGALA M., POPOV A. V., RIBARIC D. 1996. Bioacoustics of singing cicadas of the western Palaearctic: *Cicadetta tibialis* (Panzer) (Cicadoidea: Tibicinidae). Acta Ent. Slov., **4**: 45-62

HEATH J. E., WILKIN P. J. 1970. Temperature responses of the desert cicada, *Diceroprocta apache* (Homoptera, Cicadidae). Physiol. Zool., **43**: 145-154.

JOSEPHSON R. K., YOUNG D. 1979. Body temperature and singing in the bladder cicada, *Cystosoma saundersii*. J. Exp. Biol., **80**: 69-81.

POPOV A.V. 1975. The structure of the tymbals and the characteristics of the sound signals in singing cicadas (Homoptera, Cicadidae) in the southern regions of the USSR. Entomol. Rev., **54**: 7-35.

POPOV A.V., BEGANOVIC A., GOGALA M. 1996. Bioacoustics of singing cicadas of the western Palaeartic: *Tettigeta brullei* (FEIBER, 1876) (Cicadoidea: Tibicinidae). Acta Entomol. Slov., **5**: 89-101.

QUARTAU J. A. 1995. Cigarras, esses insectos quase desconhecidos. Correio da Natureza, **19**: 33-38.

QUARTAU J. A., REBELO M. T. 1994. Sinais acústicos em Cicadidae e Cicadellidae (Homoptera, Auchenorrhyncha). Actas do I Congresso Nacional de Etologia: 137-142.

QUARTAU J. A., REBELO M. T., SIMÕES P. C., FERNANDES T. M., CLARIDGE M. F., DROSOPOULOS S., MORGAN J. C. 1999. Acoustic signals of populations of *Cicada orni* L. in Portugal and Greece (Homoptera: Auchenorrhyncha: Cicadidae). Reichenbachia, **33**(1): 71-80.

SANBORN A. F. 1997a. Thermal biology of cicadas (Homoptera: Cicadoidea). Trends in Entomology, **1**: 89-104.

SANBORN A. F. 1997b. Body temperature and the acoustic behavior of the cicada *Tibicen winnemanna* (Homoptera: Cicadidae). J. Insect Behav., **10**(2): 257- 264.

SANBORN A. F., PHILLIPS P. K. 1992. Observations on the effect of a partial solar eclipse on calling in some desert cicadas (Homoptera: Cicadidae). Fla Entomol., **75**(2): 285-287.

SIMMONS P., YOUNG D.1978. The tymbal mechanism and song patterns of the bladder cicada, *Cystosoma saundersii.* J. Exp. Biol., **76**: 27-45.

STIEDL O., HOFFMAN E., KALMRING K., 1994, Chirp rate variability in male song of *Ephippigerida taeniata* (Orthoptera: Ensifera). J. Insect Behav., **7**(2): 171-181.

TOOLSON E. C. 1987. Water profligacy as an adaptation to hot deserts: water loss rates and evaporative cooling in the Sonoran Desert cicada, *Diceroprocta apache* (Homopytera: Cicadidae). Physiol. Zool., **60**: 379-385.

VILLET M. 1992. Responses of free-living cicadas (Homoptera: Cicadidae) to broadcasts of cicada song. J. Ent. Soc. South Afr., **55**(1): 93-97.

WALKER T. J. 1998. Trilling field crickets in a zone of overlap (Orthoptera: Gryllidae: *Gryllus*). Ann. Entomol. Soc. Am., **91**(2): 175-184.

YOUNG D., JOSEPHSON R. K. 1983. Pure-tone songs in cicadas with special reference to the genus *Magicicada*. J. Comp. Physiol. A., Sensory, Neural, and Behavioral Physiology, **152**: 197-207.