Analysis of Acoustic Signals Produced by the Cicada *Platypedia putnami* Variety *lutea* (Homoptera: Tibicinidae)

ALLEN F. SANBORN[1] AND POLLY K. PHILLIPS[2]

Ann. Entomol. Soc. Am. 92(3): 451–455 (1999)

ABSTRACT Most male cicadas produce calling songs to attract females, and most cicadas use a specialized timbal organ to produce sound. However, several cicada genera can produce acoustic signals through stridulation or crepitation either in addition to or in place of the timbal song. We analyzed the acoustic signals produced by a crepitating cicada, *Platypedia putnami* variety *lutea* Davis. Peak frequency of the sound pulses produced by crepitation were determined to be 10.18 and 9.66 kHz for males and females, respectively. Individual pulse duration was ≈10 ms. Males produced pulses at a rate of 8.68 Hz and females produced pulses at a rate of 18.76 Hz. We found a delay of ≈40 ms between a male pulse and the response by a female. The mean sound pressure level (89.7 dB) of crepitating *P. putnami* variety *lutea* did not differ significantly from the predicted value, based on the regression of call intensity as a function of body mass for cicadas producing timbal songs previously published.

KEY WORDS *Platypedia putnami,* cicadas, acoustic behavior, sound pressure level, crepitation, timbal song

Most male cicadas produce a loud mating call to attract females for reproduction. The most common structure used by cicadas to produce these calls is a timbal organ. The timbal organ is a rigid, chitinous membrane strengthened by ribs on the dorsolateral surface of the 1st abdominal segment. Sound pulses are produced when the timbal muscles buckle the timbal and the ribs (Pringle 1954, Bennet-Clark 1998). The rapid buckling of these timbal organs produces the characteristic song of most cicadas.

Another method of sound generation used by cicadas is stridulation. A stridulating apparatus has been described or observed in cicada genera from around the world (Davis 1943; Torres 1958; Boulard 1973, 1975, 1976, 1986, 1990; Moore 1973). The typical stridulating apparatus is a file and scraper system similar to that found in crickets, grasshoppers, and some heteropterans. The stridulating apparatus normally is found associated with the tegmina and the mesonotum (Jacobi 1907; Torres 1958; Boulard 1973, 1975, 1976, 1990; Moore 1973), but 1 stridulatory apparatus also has been described as a modification of the genitalia (Boulard 1986).

Cicadas of the North American genus *Platypedia* Uhler have lost the ability to use their timbals and communicate through a 3rd mechanism of sound production, crepitation (Moore 1966, 1973, 1993). Although sound production in the genus *Platypedia* has been described as stridulation (Davis 1943, Simons 1954), no file or scraper has been described on the wings. Instead, the wings are snapped together or banged on vegetation to make sound pulses (Moore 1966, 1973). Sound production through crepitation has also been described for several other genera of cicadas (Dugdale and Fleming 1969, Moore 1973, Duffels 1988). Both sexes of *Platypedia* produce acoustic signals, thus providing a 2-way communication system between males and females (Davis 1943). In contrast, cicadas that use timbal organs are restricted to a unidirectional information transfer from males to females. The 2-way communication system of the crepitating and stridulating species provides an additional means to ensure species identification. However, there may be acoustic costs associated with crepitation.

We begin an analysis of the communication system of *P. putnami* variety *lutea* Davis with an acoustic analysis of the mating signals produced during crepitation. We were also curious as to how the sound pressure level of a song produced by crepitation would compare with timbal song sound pressure levels. Here we compare the sound pressure levels of the crepitating species to the calls produced with timbal organs using the regression we have already produced for cicadas producing acoustic signals with timbal organs (Sanborn and Phillips 1995).

Materials and Methods

Crepitations were recorded from animals active in the field during June 1995 on Mt. Lemmon, Pima County, AZ, at an altitude of 1,981 m. Ambient temperature was 23–25°C when the recordings were made. Individuals were recorded using an Uher 4000 Report Monitor tape deck (Munich, Germany) and a Sennheiser MKH 70 P 48 directional microphone

[1] Barry University, School of Natural and Health Sciences, 11300 NE Second Avenue, Miami Shores, FL 33161–6695.
[2] Current address: 15830 SW 3rd Court, #203, Pembroke Pines, FL 33027.

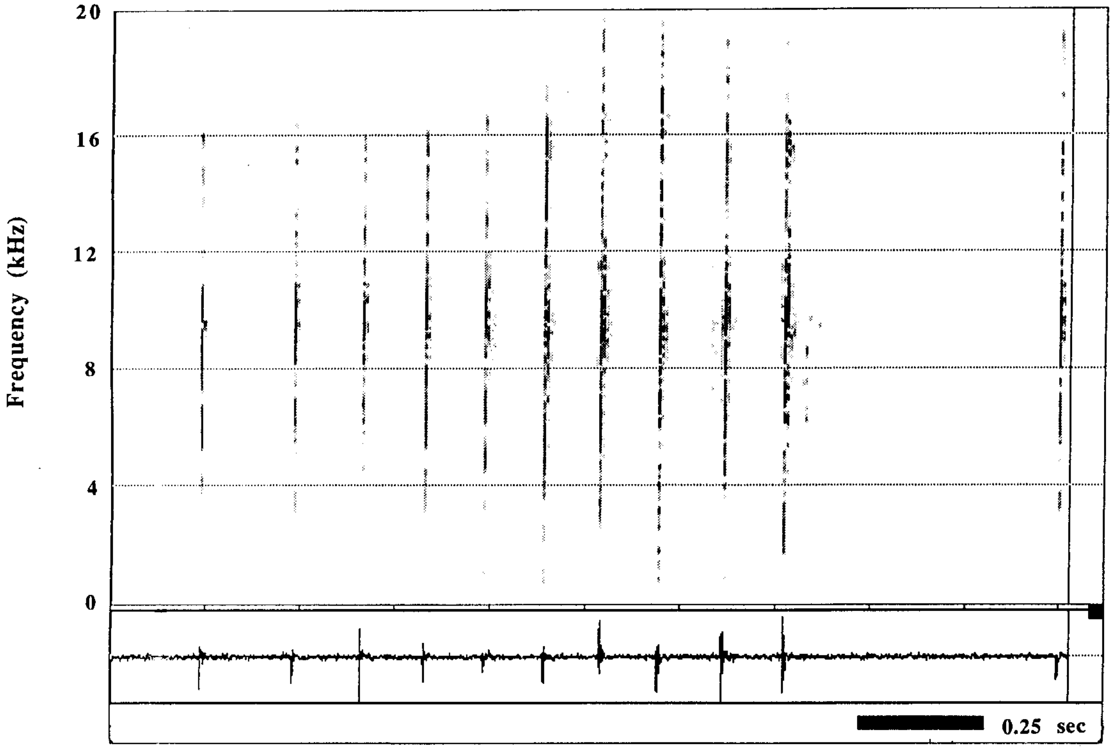

Fig. 1. Sonagram of the sound pulses produced by *P. putnami* variety *lutea.* Frequency range is 0–20 kHz. Total time of the trace is 2.026 s. Time bar = 0.25 s.

(Wedemark, Germany) with an MZW 70 wind screen. Frequency response range of the recording equipment is 50–20,000 Hz. All calls were recorded on 1.9-cm audio tape at a tape speed of 19 cm s^{-1}. The microphone was placed within 0.5 m from the calling animal in an effort to decrease background noise on the recording. MacSpeech Lab II (GW Instruments, Somerville, MA) and a Macintosh computer were used to analyze the signals. Recordings were digitized at a sampling rate of 40 kHz. Frequency spectra were analyzed using a narrow band FFT.

Peak sound pressure levels were recorded with a Brüel & Kjaer (Naerum, Denmark) 2235 SPL meter, a Type 4155 ½″ prepolarized condenser microphone, and an UA 0237 wind screen with a flat response to 16 kHz. The instrument was oriented medially along the dorsal side of a singing cicada perpendicular to the long body axis. This procedure minimized any inconsistencies among readings caused by possible asymmetries in the sound field of cicadas (Aidley 1969, MacNally and Young 1981). Each intensity measurement was made at a distance of 50 cm from the calling cicada. The distance was kept constant by placing a 6.35 mm (0.25") dowel attached to the sound pressure level meter near a calling cicada. If the cicada was disturbed by placement of the instrumentation, a reading was made only after the normal calling pattern had been reestablished. All intensity measurements are relative to 1×10^{-12} W m^{-2}.

Power output was determined using the following equation:

$$Q = 4\pi r^2(I),$$

where Q = sound power, r = distance from source in cm (=50 cm), and I = intensity reading for the individual. Because intensity (decibels) is measured on a logarithmic scale, all sound pressure level measurements were converted to power levels (watts) before calculating the statistics. Mean power output was used to calculate mean sound intensity at 50 cm for each species.

Live weight of the cicadas was determined with a Cent-O-Gram triple beam balance (Ohaus Scale, Florham Park, NJ) sensitive to ±5 mg. Weight measurements were recorded within 12 h of the specimens being collected. All statistics are reported as mean ± SD.

Results

Platypedia putnami variety *lutea* is a small cicada (303 ± 47 mg [n = 35]) that forms aggregations in manzanita (*Arctostaphylos* sp.). Individual sound pulses are produced during crepitation in *P. putnami* variety *lutea* as the wings slap above or onto the animal. The result is a broad band frequency sound pulse (Fig. 1). Major energy is between 4 and 16 kHz with

Table 1. Summary analysis for the signals produced by crepitation of *P. putnami* variety *lutea*

Acoustic parameter	Males	Females
Peak frequency, kHz	10.18 ± 0.74 (n = 10)	9.66 ± 0.40 (n = 6)
Pulse duration, ms	10.33 ± 5.85 (n = 10)	9.82 ± 3.39 (n = 6)
Pulse repetition rate, Hz	8.68 ± 3.35 (n = 10)	18.76 ± 14.80 (n = 4)
Delay between male and female signals, ms	39.75 ± 1.77 (n = 2)	

Data presented are the means for the population determined from mean values of the acoustic parameter for individual animals (n = 1–13).

peak energy at ≈10 kHz. A summary of the characteristics of *P. putnami* variety *lutea* crepitations is provided in Table 1. Fig. 2 illustrates the acoustic interaction between a male and female *P. putnami* variety *lutea.* The female answered the male click after ≈35 ms.

The sound pressure levels measured for *P. putnami* variety *lutea* averaged 89.7 dB or 2.96 ± 0.521 mW (n = 14). There was no statistical difference between the sound pressure levels of pulses produced by males and females during crepitation (t = 0.009, df = 12, P = 0.5036); thus, sound pressure levels and mass data were combined for comparisons with the regression of timballing species.

When the datum for *P. putnami* variety *lutea* sound pressure level is plotted on the regression of sound pressure level as a function of body mass in cicadas (Sanborn and Phillips 1995) (Fig. 3), the sound pressure level of the signal produced by crepitation is similar to the expected value for a cicada of its size producing a song with a timbal apparatus.

Discussion

There is nothing unusual about the individual sound pulses produced by crepitation in *P. putnami* variety *lutea.* The sound pulses are produced in *P. putnami* variety *lutea* as the cicada slaps the wings together over the body or as the wings slap the body surface. Moore (1973, 1993) described crepitating cicadas producing sound by banging their forewings against vegetation. Substrate banging is not necessary to produce sound in *P. putnami* variety *lutea,*

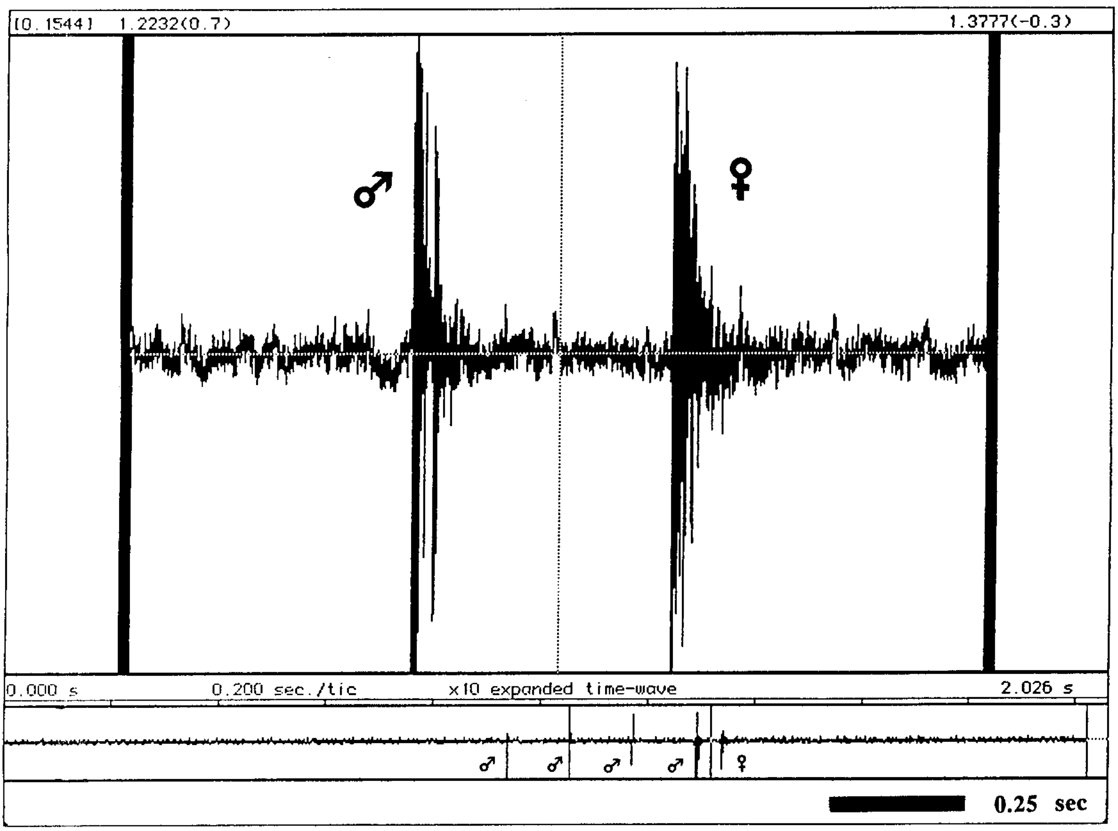

Fig. 2. Oscillogram of the interaction between male and female specimens of *P. putnami* variety *lutea.* The lower trace illustrates 4 pulses of a male followed by a single answer pulse produced by the female. The female responded ≈35 ms after the male finished crepitating. The expanded waveform provides a better illustration of the last male pulse and the pulse produced by the female. Total time of the trace is 2.026 s. Time bar = 0.25 s.

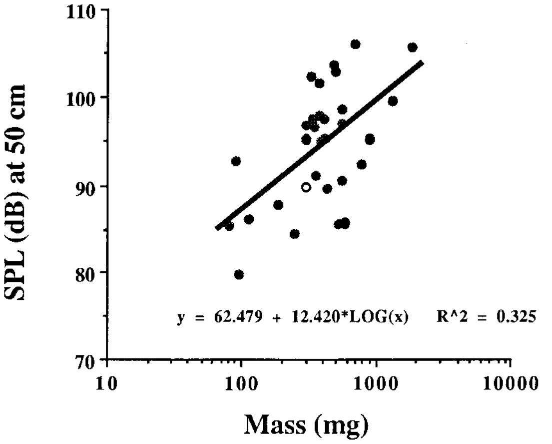

Fig. 3. Mean call intensity at 50 cm as a function of mean body mass for cicadas. Call intensity is the value calculated from the mean power output determined for each species ($n = 1$–40). Mean body mass is the value determined for each species, not the specific individuals that were calling ($n =$ 10–214). The datum for the crepitating *P. putnami* variety *lutea* (open circle) falls near the regression for the 30 species producing timbal songs tested by Sanborn and Phillips (1995).

because the cicadas could produce sound pulses while perched on a flaccid towel hung over the back of a chair during thermal experiments in the laboratory. The pulses appeared to be similar in their physical characteristics and intensity in both the laboratory and the field. We therefore conclude that substrate banging is not necessary for producing the sound pulses in *P. putnami* variety *lutea,* because although the towel moved when struck by the forewing, the sound was not attenuated because of absorption by the fabric.

The acoustic characteristics of the pulses are determined by the physical properties and anatomy of the acoustic system as in any signal produced by vibrating body parts (Bennet-Clark 1989, 1995). Each movement of the wings is responsible for producing a single pulse. Trains of pulses (as seen in Fig. 1) are caused by multiple movements of the wings.

The measurements of crepitation intensity in the field showed that *P. putnami* variety *lutea* did not differ from the expected regression of sound pressure level as a function of body mass described previously (Sanborn and Phillips 1995). Further analysis and comparisons are difficult because of the different nature of the sound producing systems (see Bennet-Clark [1995, 1998] for a discussion of the differences in the physics of the systems).

It has been shown (Heath et al. 1971, 1972; Sanborn et al. 1992, 1995a, b) that calling occurs over a limited range of body temperature (T_b), and that this range is much less than the T_b range permitting flight. Thus, the use of the wing musculature may permit crepitation over a greater range of T_b and therefore increase the T_b range over which the *Platypedia* can produce acoustic signals.

The short duration and amplitude of the wing movements during crepitation could save the crepitating species significant amounts of energy over a timbal song. The metabolic rate of cicadas calling with timbals increases >18 times over the resting metabolic rate in *Cystosoma saundersii* Westwood (MacNally and Young 1981). A comparison of the energetic cost of crepitation in cicadas and timbal songs would prove interesting.

Acknowledgments

Thomas Moore and an anonymous reviewer made suggestions that improved the manuscript. Maxine Heath of the University of Illinois confirmed the identification of the species used in this study. A.F.S. thanks John Karen Frei of Barry University for financial support.

References Cited

Aidley, D. J. 1969. Sound production in a Brazilian cicada. J. Exp. Biol. 51: 325–337.

Bennet-Clark, H. C. 1989. Songs and the physics of sound production, pp. 227–261. *In* F. Huber, T. E. Moore, and W. Loher [eds.], Cricket behavior and neurobiology. Cornell University Press, Ithaca, NY.

1995. Insect sound production: Transduction mechanisms and impedance matching. Symp. Soc. Exp. Biol. 49: 199–218.

1998. Size and scale effects as constraints in insect sound communication. Philos. Trans. R. Soc. Lond. B 353: 407–419.

Boulard, M. 1973. Les *Ydiellinae:* sous-famile nouvelle de cigales *Platypediidae.* Clé des familles et sous-familles des Homopteres Cicadoidea. Ann. Soc. Entomol. Fr. 9: 841–852.

1975. Sur une deuxime cigale africaine depourvue d'appareil sonore (Homoptera). Bull. Inst. Fond. Afr. Noire (Ser. A) 37: 629–636.

1976. Un type nouveau d'appareil stridulant accessoire pour les Cicadoidea. Revision de la classification supérieure de la superfamille (Hom.). J. Nat. Hist. 10: 399–407.

1986. Une singulíere évolution morphologique: celle d'un appariel stridulant sur les genitalia des males de *Carineta.* Description de cinq especies nouvelles (Hom. Tibicinidae). Ann. Soc. Entomol. Fr. 22: 191–204.

1990. Contributions à l'entomologie générale et appliquée 2. Cicadaires (Homoptéres Auchenorhynques). Primiére partie: Cicadoidea. EPHE Trav. Lab. Biol. Evol. Ins. 3: 55–245.

Davis, W. T. 1943. Two ways of song communication among our North American cicadas. J. N.Y. Entomol. Soc. 51: 185–190.

Duffels, J. P. 1988. The cicadas of Fiji, Samoa, and Tonga Islands, their taxonomy and biogeography (Homoptera, Cicadoidea) with a chapter on the geological history of the area by A. Ewart. Entomonogr. 10: 1–108.

Dugdale, J. S., and C. A. Fleming. 1969. Two New Zealand cicadas collected on Cook's Endeavour voyage, with descriptions of new species. N.Z. J. Sci. 12: 929–957.

Heath, J. E., J. L. Hanagan, P. J. Wilkin, and M. S. Heath. 1971. Adaptation of the thermal responses of insects. Am. Zool. 11: 147–158.

Heath, J. E., P. J. Wilkin, and M. S. Heath. 1972. Temperature responses of the cactus dodger, *Cacama valvata* (Homoptera, Cicadidae). Physiol. Zool. 45: 238–246.

Jacobi, A. 1907. Ein Schrillapparat bei Singcicaden. Zool. Anz. 32: 67–71.

MacNally, R. C., and D. Young. 1981. Song energetics of the bladder cicada, *Cystosoma saundersii.* J. Exp. Biol. 90: 185–196.

Moore, T. E. 1966. The cicadas of Michigan (Homoptera: Cicadidae). Pap. Mich. Acad. Sci. 51: 75–96.

1973. Acoustical communication in insects, pp. 307–323. *In* V. Tipton [ed.], Introductory entomology. BYU Press, Ogden, UT.

1993. Acoustic signals and speciation in cicadas (Insecta: Homoptera: Cicadidae), pp. 269–284. *In* D. R. Lees and D. Edwards [eds.], Evolutionary patterns and processes. Linnean Society Symposium Series 14. Academic, London.

Pringle, J.W.S. 1954. A physiological analysis of cicada song. J. Exp. Biol. 31: 525–560.

Sanborn, A. F., J. E. Heath, and M. S. Heath. 1992. Thermoregulation and evaporative cooling in the cicada *Okanagodes gracilis* (Homoptera: Cicadidae). Comp. Biochem. Physiol. 102A: 751–757.

Sanborn, A. F., and P. K. Phillips. 1995. Scaling of sound pressure level and body size in cicadas (Homoptera: Cicadidae: Tibicinidae). Ann. Entomol. Soc. Am. 88: 479–484.

Sanborn, A. F., J. E. Heath, F. G. Noriega, and M. S. Heath. 1995a. Thermoregulation by endogenous heat production in two South American grass dwelling cicadas (Homoptera: Cicadidae: *Proarna*). Fla. Entomol. 78: 319–328.

Sanborn, A. F., M. S. Heath, J. E. Heath, and F. G. Noriega. 1995b. Diurnal activity, temperature responses, and endothermy in three South American cicadas (Homoptera: Cicadidae: *Dorisiana bonaerensis*, *Quesada gigas* and *Fidicina mannifera*). J. Therm. Biol. 20: 451–460.

Simons, J. N. 1954. The cicadas of California. Bull. Calif. Insect Surv. 2: 153–192.

Torres, B. A. 1958. Revision del genero "*Tettigades*" Amy. et Serv. (Homoptera-Cicadidae). Rev. Mus. La Plata 53: 51–106.

Received for publication 2 April 1998; accepted 1 February 1999.