

Scaling of Sound Pressure Level and Body Size in Cicadas (Homoptera: Cicadidae; Tibicinidae)

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ABSTRACT We measured the sound pressure level of the calling songs of 30 species and the alarm calls of 59 species of North American cicadas. Mean calling song sound pressure levels ranged from 79.8 to 106.2 dB, whereas mean alarm call sound pressure levels ranged from 75.3 to 105.9 dB, which is within the range of values reported in the literature for other cicada species. The peak sound pressure level of 108.0 dB was measured in a calling *Tibicen winnemanna* (Davis) and 108.9 dB in an alarm call produced by *T. walkeri* Metcalf. Maximum power values were 198.2 mW for a calling cicada and 243.9 mW during alarm production. Sound pressure level increased as body mass increased for both the calling song and the alarm call. This may be caused by larger timbal muscles or more efficient resonating structures in the larger species. Variability in the sound intensity measured for a particular species may be caused by factors such as age, physiological state, or the presence of rivals in the habitat. Large body size may benefit a species because louder calls increase broadcast area and potential interaction with members of their species.

KEY WORDS sound pressure level, scaling, acoustic communication

MOST MALE CICADAS attract their mates by producing a loud calling song. Sound is produced when muscles buckle the rib-strengthened chitinous membranes, the timbals, located on the dorso-lateral surface of the first abdominal segment. The sound pulse is then modified by several body components (Pringle 1954, Bennet-Clark and Young 1992) before being radiated through the tympana (Young 1990). Sound frequency has been shown recently to correlate with body mass and body size in cicadas (Daniel et al. 1993, Bennet-Clark and Young 1994).

The sound pressure level produced by a calling cicada is modified by anatomical structures and physiological conditions. Sound pressure level is increased through the resonance of the abdominal air sacs (Pringle 1954, Moore and Sawyer 1966, Young 1972, Jiang et al. 1986, Weber et al. 1987, Bennet-Clark and Young 1992, Hennig et al. 1994) or by placing tension on the timbal (Pringle 1954, Aidley 1969, Hennig et al. 1994). Timbal muscle tension, which is dependent on temperature, also affects sound pressure level (Josephson and Young 1979).

There has been only 1 previous study specifically dealing with sound pressure levels in cicadas (Villet 1987). That study dealt with 7 species. We report here the sound pressure levels from 59 species of North American cicadas that were producing their species specific calling song or their alarm call (protest song) or both. We examine the relation-

ship between body mass and the sound pressure level produced by the different cicada species.

Materials and Methods

Peak sound pressure level was recorded with a Brüel & Kjaer 2235 SPL meter, a type 4155, ½" prepolarized condenser microphone and a UA 0237 wind screen calibrated with a Brüel & Kjaer 4230 portable sound pressure calibrator. The peak time weighting setting used has a time constant of <100 μs and was used to ensure that any rapid sound transients were measured. The apparatus was oriented medially along the dorsal side of a singing cicada with each measurement perpendicular to the long body axis. This procedure minimized any inconsistencies between readings caused by possible asymmetries in the sound field produced by cicadas (Aidley 1969, MacNally and Young 1981, Young 1990). Each sound pressure level measurement was made at a distance of 50 cm. Measurements made at 50 cm are in the far field and, therefore, no corrections need be made for near field pressure effects (Michelsen and Nocke 1974). The distance was kept constant by placing a ¼" dowel that was attached to the meter near a calling cicada and was generally far enough from the cicadas so their calling patterns were not disturbed. If a cicada was disturbed by placement of the instrumentation, a reading was made only after the normal calling pattern had been reesta-

blished by the insect. All measurements are relative to 1×10^{-16} W/cm². There was no vegetation between a calling cicada and the microphone during measurements in the field. All measurements of calling song intensity were made in the field.

All alarm call intensities were measured in the laboratory rather than in the field to permit us to correlate individual mass and sound pressure level measurements. Alarm calls were initiated by manipulating an insect in the laboratory. This enabled us to coordinate individual alarm call sound pressure level values with the live weight of each insect. To determine alarm call sound pressure level, individual cicadas were rotated in space at a distance of 50 cm from the microphone while the cicada was producing the alarm call for 30 s to 1 min. This procedure was used to eliminate any variation between species caused by possible asymmetries in the sound field or body positioning caused by mechanical disturbances as a result of handling by the experimenter. The alarm call measurements were taken after the animals had reached the maximum voluntary tolerance temperature in the laboratory. This body temperature represents an upper thermoregulatory temperature (Heath 1970) and the animals, therefore, should be within the body temperature range of normal activity.

Power output was determined using the following equation: $Q = 4\pi r^2 I$ where Q = sound power (W), r = distance from source in cm (50 cm), and I = intensity (calculated from the sound pressure level reading [decibels] for the individual). Because sound pressure level is measured on a logarithmic scale, all measurements (decibel readings) were converted to power levels (watts) before calculating statistical measures. Mean power output was then used to calculate mean sound pressure level at 50 cm for each species.

Live weights for each species were measured with a triple beam balance (Cent-O-Gram Model CG 311, Ohaus Scale, Florham Park, NJ) sensitive to ± 5 mg. The body mass value for each species is the mean value determined for the males of that species when scaling calling song sound pressure level (species number ranges from 9 to 223). An individual body mass value for each alarm call sound pressure level was made possible by the procedures outlined above when scaling alarm calls. All statistics are reported as mean \pm SD.

Fifty-nine species from 10 genera and 2 families were collected during June, July, and August of 1991, 1993, and 1994. All species are typical cicadas of similar design without unique adaptations to increase sound output such as the highly extensible abdomen of the bladder cicada *Cystosoma saundersii* Westwood (Simmons and Young 1978). Species identifications were confirmed or made by Maxine S. Heath at the University of Illinois. There are several new species and a new variety identified in the data, which are in the process of being described by Heath et al. The data for *P.*

puella Davis is separated by the host plant on which the individuals were captured. *P. puella* appears to be 2 separate species with different host plant preferences (Heath et al., unpublished data).

Results

Sound pressure levels and calculated sound power for the species used in this study are summarized in Table 1. Mean call ranges from 79.8 to 106.2 dB and mean alarm ranges from 75.3 to 105.9 dB. This corresponds to mean power ranges of 0.298–129.86 mW and 0.107–122.7 mW, respectively. The maximum sound pressure level recorded for a calling individual was 108.0 dB in *T. winnemanna* (Davis). Maximum sound pressure level for an individual producing an alarm call was 108.9 dB in *T. walkeri* Metcalf. Maximum power values are 198.2 mW for a calling cicada and 243.9 mW during alarm production.

Diceroprocta delicata (Osborn), *D. olympusa* (Walker), *D. swalei* (Distant), *Okanagana hesperia* (Uhler), *O. striatipes* (Haldeman), *O. utahensis* Davis, *Okanagodes terlingua* Davis, and the mesquite variety of *P. puella* showed less than a 2-dB variation between individual calling song sound pressure levels. For other species there is a greater amount of variability within a species.

Physiological state can alter the sound pressure levels of cicada calls. The acoustic output of *T. winnemanna* varies with thoracic temperature, proceeding from a constant buzzing at low body temperature, through a call that begins as a buzz and terminates with a few frequency modulations, a slow frequency modulated call, and finally the full calling song, while the animals warm endothermically at dusk (Sanborn 1990). We found that sound pressure level increases as *T. winnemanna* proceeds to full song production. Although sound pressure level changes with the type of call produced, there is also considerable variation within a single type of call.

The sound pressure level of both the calling songs and alarm calls show a tendency to increase with increasing body mass (Figs. 1 and 2). The slope of the regression line is nearly the same and is highly significant for both types of calls. The increase in calling song sound pressure level as a function of body mass is described by the equation $Y = 62.554 + 12.420 \log(\text{mass})$ ($R = 0.570$; $F = 13.482$; $df = 1, 28$; $P = 0.001$). The increase in alarm call sound pressure level with mass and is described by the relationship $Y = 61.934 + 12.856 \log(\text{mass})$ ($R = 0.672$; $F = 331.043$; $df = 1, 403$; $P < 0.0001$).

Discussion

Sound pressure levels we recorded are similar to pressure level values determined for other cicada species after correcting for measurement distance. Mean values for cicada species reported in the lit-

Table 1. Song power and sound pressure levels of some North American cicada calls

Species	Power, mW	Sound pressure level, dB	Range, dB
<i>Beameria venosa</i> (Uhler)	1.04 ± 0.102 call	85.2 (21)	81.7–88.3
	1.48 ± 2.414 alarm	86.7 (30)	78.1–94.6
<i>Beameria wheeleri</i> Davis	2.67 alarm	89.3 (1)	89.3
<i>Beameria</i> n. sp.	1.29 ± 1.026 call	86.1 (12)	80.2–91.1
	7.97 ± 2.545 alarm	94.0 (4)	92.4–95.4
<i>Cacama calvata</i> (Uhler)	11.19 ± 4.557 alarm	95.5 (8)	92.4–98.2
<i>Cacama</i> n. sp. 1	10.89 alarm	95.4 (1)	95.4
<i>Cacama</i> n. sp. 2	13.71 ± 2.037 alarm	96.4 (2)	95.7–97.1
<i>Clidophleps distanti</i> (Van Duzee)	7.03 alarm	93.5 (1)	93.5
<i>Cornuplura nigroalbata</i> (Davis)	64.25 ± 44.401 alarm	103.1 (16)	88.1–107.4
<i>Diceroprocta apache</i> (Davis)	129.86 ± 52.227 call	106.2 (8)	102.3–107.9
	90.97 ± 51.131 alarm	104.6 (23)	100.3–108.0
<i>Diceroprocta azteca</i> (Distant)	39.68 ± 21.818 alarm	101.0 (8)	94.1–103.4
<i>Diceroprocta bibbyi</i> Davis	17.78 ± 8.727 call	97.5 (13)	91.7–100.2
	25.57 ± 19.209 alarm	99.1 (27)	91.9–102.7
<i>Diceroprocta biconica</i> (Walker)	48.20 ± 24.364 alarm	101.9 (11)	96.7–104.3
<i>Diceroprocta canescens</i> Davis	22.76 call	98.6 (1)	98.6
	31.28 ± 19.897 alarm	100.0 (10)	96.4–103.3
<i>Diceroprocta cinctifera</i> (Uhler)	38.75 ± 23.158 alarm	100.9 (13)	95.4–104.3
<i>Diceroprocta cinctifera</i> var. <i>limpia</i> Davis	90.22 ± 59.585 alarm	104.6 (10)	98.0–108.4
<i>Diceroprocta cinctifera</i> var. <i>viridicosta</i> Davis	81.71 ± 20.927 alarm	104.2 (9)	100.8–105.6
<i>Diceroprocta delicata</i> (Osborn)	10.49 ± 2.164 call	95.2 (4)	94.6–96.4
	9.81 ± 4.044 alarm	95.0 (10)	91.7–97.5
<i>Diceroprocta delicata</i> var. <i>aurantiaca</i> Davis	19.61 ± 6.828 cal	98.0 (6)	96.2–100.0
	11.32 ± 6.025 alarm	95.6 (16)	91.9–99.2
<i>Diceroprocta eugraphica</i> (Davis)	9.57 ± 3.788 call	94.8 (18)	89.7–97.1
	13.46 ± 10.632 alarm	96.3 (19)	88.9–101.6
<i>Diceroprocta knighti</i> (Davis)	46.97 ± 19.119 call	101.8 (13)	98.5–104.3
	30.82 ± 25.629 alarm	99.9 (16)	94.8–105.6
<i>Diceroprocta olympusa</i> (Walker)	17.28 ± 3.920 call	97.4 (3)	96.6–98.4
	23.69 ± 11.035 alarm	98.8 (5)	95.2–100.8
<i>Diceroprocta semicincta</i> (Davis)	73.22 ± 44.106 call	103.7 (10)	100.8–107.7
	49.53 ± 25.188 alarm	102.0 (9)	98.9–104.7
<i>Diceroprocta semicincta</i> var. n.	48.53 ± 37.634 alarm	101.9 (3)	97.6–104.6
<i>Diceroprocta swalei</i> (Distant)	14.38 ± 0.278 call	96.6 (8)	96.3–96.9
	10.85 ± 4.098 alarm	95.4 (11)	90.2–97.1
<i>Diceroprocta texana</i> (Davis)	10.87 ± 3.684 call	95.4 (7)	92.7–97.1
	29.24 ± 15.081 alarm	99.7 (7)	95.1–102.3
<i>Diceroprocta texana</i> var. <i>lata</i> Davis	62.22 ± 28.667 call	103.0 (4)	99.7–104.9
	42.88 ± 24.789 alarm	101.4 (6)	96.0–103.8
<i>Neocicada chisos</i> (Davis)	17.52 ± 5.476 call	97.5 (3)	96.5–98.8
	7.52 ± 4.092 alarm	93.8 (3)	91.8–95.9
<i>Neocicada hieroglyphica</i> (Say)	53.19 ± 12.902 call	102.3 (4)	101.4–103.6
	5.10 alarm	92.1 (1)	92.1
<i>Okanagana annulata</i> Davis	6.97 ± 1.402 alarm	93.5 (3)	92.7–94.4
<i>Okanagana bella</i> (Davis)	10.36 ± 4.612 alarm	95.2 (10)	90.9–96.9
<i>Okanagana canadensis</i> (Provancher)	19.32 ± 12.271 alarm	97.9 (2)	95.3–99.5
<i>Okanagana cruentifera</i> (Uhler)	14.03 alarm	96.5 (1)	96.5
<i>Okanagana hesperia</i> (Uhler)	3.97 ± 0.591 call	91.0 (9)	89.6–91.6
	4.90 ± 2.229 alarm	91.9 (11)	85.0–94.3
<i>Okanagana magnifica</i> Davis	3.22 alarm	90.1 (1)	90.1
<i>Okanagana pallidula</i> Davis	1.11 ± 0.682 call	85.5 (3)	83.4–87.8
	0.468 ± 0.1852 alarm	81.7 (2)	80.3–82.8
<i>Okanagana striatipes</i> (Haldeman)	2.89 ± 0.444 call	89.6 (11)	88.7–90.5
	6.81 ± 3.076 alarm	93.4 (26)	89.2–96.7
<i>Okanagana sugdeni</i> Davis	27.96 ± 12.805 alarm	99.5 (13)	95.0–102.6
<i>Okanagana synodica</i> (Say)	2.61 alarm	89.2 (1)	89.2
<i>Okanagana tristris</i> Van Duzee	8.85 alarm	94.5 (1)	94.5
<i>Okanagana utahensis</i> Davis	1.13 ± 0.066 call	85.5 (3)	85.3–85.8
	5.41 ± 3.846 alarm	92.4 (12)	79.2–96.6
<i>Okanagodes gracilis</i> Davis	0.842 ± 0.351 call	84.3 (9)	79.5–86.4
	1.40 ± 1.037 alarm	86.5 (14)	76.0–90.8
<i>Okanagodes terlingua</i> Davis	0.919 ± 0.0742 call	84.7 (8)	84.1–85.2
	2.20 ± 1.422 alarm	88.5 (13)	82.0–89.6
<i>Pacarina puella</i> Davis (juniper variety)	5.78 ± 2.967 call	92.7 (3)	90.2–94.6
	3.07 ± 0.850 alarm	89.9 (5)	88.6–91.5
<i>Pacarina puella</i> Davis (mesquite variety)	0.298 ± 0.0338 call	79.8 (2)	79.4–80.1
	0.107 ± 0.0612 alarm	75.3 (4)	71.0–78.1
<i>Tibicen canicularis</i> (Harris)	45.40 ± 17.071 alarm	101.6 (6)	98.7–103.3
<i>Tibicen chiricahua</i> Davis	35.24 ± 0.790 call	90.5 (6)	89.4–92.0
	20.15 ± 3.211 alarm	98.1 (3)	97.3–98.7
<i>Tibicen chisoensis</i> Davis	11.08 ± 3.532 alarm	95.5 (8)	93.6–97.5

Table 1. Continued

Species	Power, mW	Sound pressure level, dB	Range, dB
<i>Tibicen chloromerus</i> (Walker)	41.34 ± 26.538 alarm	101.2 (3)	97.1–103.4
<i>Tibicen duryi</i> Davis	5.34 ± 1.136 call	92.3 (9)	90.5–93.5
	21.14 ± 13.199 alarm	98.3 (6)	91.2–101.3
<i>Tibicen inauditus</i> Davis	15.61 ± 6.808 call	97.0 (10)	93.9–99.4
	12.95 ± 8.808 alarm	96.2 (8)	92.8–100.1
<i>Tibicen linnei</i> (Smith and Crossbeck)	99.02 ± 31.008 alarm	104.5 (14)	101.9–107.1
<i>Tibicen pruinosus</i> (Say)	45.13 ± 6.590 alarm	101.6 (2)	101.1–102.0
<i>Tibicen resh</i> (Haldeman)	122.21 ± 34.064 alarm	105.9 (4)	104.6–107.2
<i>Tibicen superbus</i> (Fitch)	28.15 ± 7.856 call	99.5 (12)	97.7–101.3
	36.56 ± 17.018 alarm	100.7 (10)	93.5–102.9
<i>Tibicen texanus</i> Metcalf	14.03 ± 0 call	95.2 (2)	95.2
	12.67 ± 12.818 alarm	96.1 (2)	90.6–98.4
<i>Tibicen townsendii</i> (Uhler)	12.66 ± 2.726 alarm	69.1 (2)	95.0–96.9
<i>Tibicen walkeri</i> Metcalf	122.68 ± 76.481 alarm	105.9 (8)	92.9–108.9
<i>Tibicen walkeri</i> var. <i>prontalis</i> Davis	110.20 ± 1.794 alarm	105.5 (2)	105.4–105.5
<i>Tibicen winemanna</i> (Davis)			
(Buzzing)	0.289 ± 0.1169	79.6 (5)	78.6–82.0
(Buzz/slow)	17.72 ± 7.684	97.5 (6)	93.5–99.4
(Slow song)	47.14 ± 19.813	101.8 (12)	98.6–101.7
(Full song)	117.73 ± 41.421 call	105.7 (40)	102.0–108.0
	84.33 ± 15.160 alarm	104.3 (12)	99.5–160.5

Because the decibel scale is logarithmic, no sound pressure level variations are given because the values will be unequal on either side of the mean. Sound pressure level measurements are relative to $1 \times 10^{-16} \text{ W/cm}^2$ ($=2 \times 10^{-4}$ dynes per square centimeter) at a distance of 50 cm. Number in parentheses is sample size.

erature have an absolute range slightly greater than we discovered in the North American cicadas. Of the 29 species for which we found sound pressure level values in the literature, only *Fidicina rana* Walker,¹ *Brevisana brevis* (Walker), and *Pycna semiclarata* (Germar) (Villet 1987) have mean call SPL greater than the mean value we determined for our loudest species, *D. apache* (Davis). Ten species have

¹ We use the name *F. rana* because the call described by Aidley (1969) is very different from the call produced by *F. mannifera* (F.) with which it was synonymized (A.F.S., unpublished data).

been described to produce sound pressure levels less than we determined for our species with the minimum call sound pressure level, the mesquite variety of *P. puella* (Alexander and Moore 1958; Popov 1981; Popov et al. 1985, 1991; Weber et al. 1987).

The absolute range of mean sound pressure level we determined for calling in the North American species was 79.8–106.2 dB. The following list provides a frame of reference for these values: library 35 dB, business office 65 dB, heavy traffic 90 dB, pneumatic chipper 105 dB, jet at take-off 125 dB (Anonymous 1984).

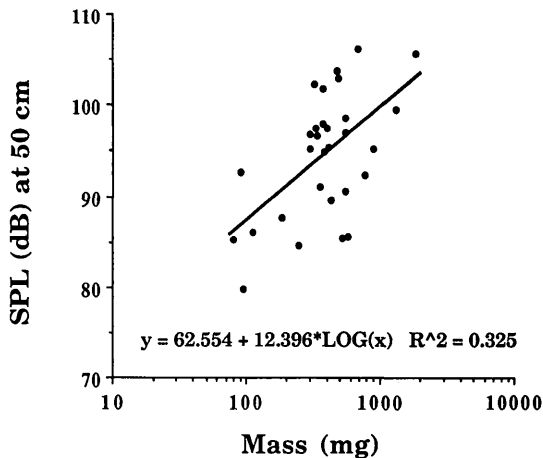


Fig. 1. Mean call sound pressure level (SPL) at 50 cm as a function of mean body mass for 30 cicada species. Call SPL was calculated from the mean power output determined for each species ($n = 1-40$). Body mass is the mean value determined for the males of each species, not the specific individuals that were calling ($n = 9-223$).

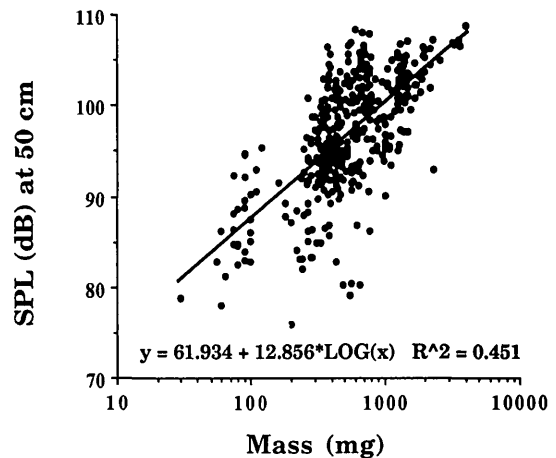


Fig. 2. Alarm call SPL as a function of body mass. The alarm calls were measured 50 cm from individual insects using the apparatus described. Each cicada was rotated in space while producing the alarm call to eliminate any variation between species caused by possible asymmetries in the sound field.

The only species sound pressure level with which we can make a direct comparison is the alarm call of *Diceroprocta apache*. Smith and Langley (1978) determined alarm call sound pressure level to be 93.07 (± 2.34) dB when standardized to 50 cm. Our value of 104.6 (+1.93, -3.59) dB is significantly greater ($t > 17$ [t ranges from 17.27 to 17.49 because of the arithmetic standard deviation of Smith and Langley around a logarithmic mean SPL], $df = 131$, $P = 0$) than the value determined by Smith and Langley (1978). The difference may be the result of the conditions used to stimulate the alarm call, measurement position, frequency weighting scale used, or the body temperature of animals when the sound pressure level was recorded.

There is no mention of specific manipulations made to the cicadas by Smith and Langley (1978) when they recorded the sound pressure level 5–10 cm from the opercula. Young (1990) has shown that this position results in a relative sound pressure level value 5 dB below the maximum obtained for *Macrotristria angularis* (Germar). Additionally, if the abdomen was prevented from exposing the tympana, the sound pressure level would be artificially depressed (Young 1990). Smith and Langley (1978) used the "A" frequency weighting on their sound pressure level meter, whereas we used the linear scale. The call of *D. apache* may fall at a frequency which is attenuated on the "A" scale. There is no mention of Smith and Langley using a peak, impulse, fast or slow time weighting. The peak setting we used will give a sound pressure level measurement greater than any of the other settings. Finally, some of the difference may be the result of the body temperature of the cicadas used in the 2 studies. Smith and Langley recorded sound pressure level at room temperature. If we assume room temperature is 20–25°C then the body temperature of the cicadas in the laboratory is well below the body temperature of normally active *D. apache* (Heath and Wilkin 1970). We have shown (Table 1) that the sound pressure level of *T. winnemanna* calls changes with the type of call produced, which is dependent on body temperature (Sanborn 1990). If the *D. apache* used by Smith and Langley were 20°C below normal operating temperature the sound pressure level measurements would be underestimated. Josephson and Young (1979) also showed that timbal muscle temperature affects sound pressure level.

The sound pressure levels of both the calling songs and alarm calls show a tendency to increase with increasing body mass. The most likely explanation for the observed relationship is the larger size of the timbal muscles in larger species. Josephson and Young (1979) showed that increases in the tension produced by the timbal muscles resulted in increased sound pressure level in *Cystosoma saundersii*. Because tension is proportional to cross-sectional area, the larger timbal muscles of larger species should provide more contractile

force. The increase in available muscle energy in larger animals can be converted to greater acoustic energy.

Another possible explanation may be a greater ability to match the resonance of the abdominal air sacs to the fundamental frequency of the timbals in larger species. One of the main difficulties that small, sound producing insects must overcome is the inefficiency of producing low frequency sounds because of poor impedance matching between radiating resonating structures (Michelsen and Nocke 1974). It may be that larger cicadas are more efficient in this impedance matching than smaller cicadas.

The extreme case of morphological adaptation to increase acoustic output in cicadas is probably illustrated by the bladder cicadas, such as *C. saundersii*. These cicadas have extremely large abdomens which increase the loudness of their call (Simmons and Young 1981). Using the mass and length values determined by MacNally and Doolan (1986), *C. saundersii* should have a call intensity of ≈ 100 dB using our regression analysis and a song frequency of ≈ 4.3 kHz using the regression analysis of Bennet-Clark and Young (1994). The actual 865 Hz song is produced at a mean intensity of 82.64 dB at 50 cm (MacNally and Young 1981). The morphological changes to the abdomen are necessary to increase the acoustic output of the unusually low frequency call in this species. The large abdomen appears to play a role in the differential behavior of the sexes in *C. saundersii* as well. The males are generally sedentary presumably because of their poor flying ability related to the large abdomen (Doolan 1981).

Many of the species we recorded showed a higher degree of variation in sound pressure level than reported by Villet (1987). The variability was observed within both species and individuals (Tables 1). The variation may be the result of factors such as age, physiological state, or the presence of rivals in the habitat. The loudest calls produced by a single *T. winnemanna* specimen during several measurements were produced when another male was singing in the same vicinity (but not close enough to alter the measurement). Any error caused by our presence should be minimal. Because we were aware that our presence could interfere with calling behavior we waited to take measurements until an individual was calling normally, if it was disturbed by our approach. In addition, we found variation in species like *Beameria venosa* (Uhler) which continue to call normally despite our approach or presence.

The results presented here suggest collateral selection for body size and sound pressure level in cicadas. We have shown that there is a tendency for larger cicadas to produce louder calls. A louder call will travel further in the environment. Larger cicadas also have lower frequency calls (Daniel et al. 1993, Bennet-Clark and Young 1994), which in general are attenuated less by the environment

(Marten and Marler 1977, Marten et al. 1977, Wiley and Richards 1978). A larger insect, therefore, has the potential to interact with a greater number of conspecific individuals without changing calling perches. Perhaps the relatively large body size of cicadas is related to their acoustic strategies of reproduction.

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