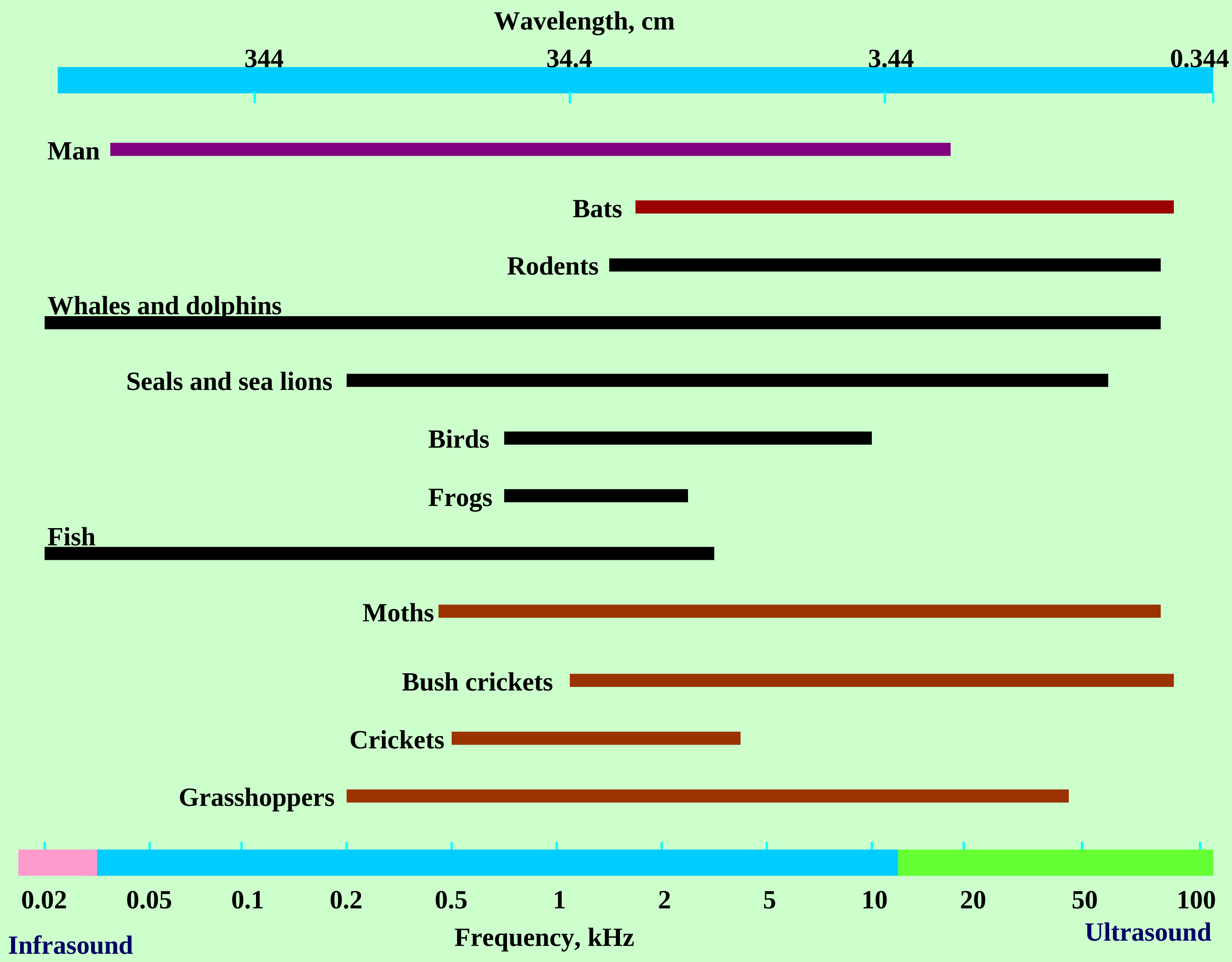
Ultrasound and Arthropod Pest Control: Hearing is Believing!

Bhadriraju Subramanyam (Subi)
Department of Grain Science and Industry
Kansas State University
Manhattan, KS 66506
bhs@wheat.ksu.edu

Seminar outline

- Introduction
- Summary of published data: efficacy tests
- Results from tests on household pests
- Results from tests on Indian meal moth (Storage pest)
- Overall conclusions
- Future research needs

Sound sensitivity in different animals (From Dusenbery, 1992)



Insects use specialized organs

- For remote sensing potential predators, prey, mates, or rivals

- To see – eyes
- To hear – auditory organs
- To smell – olfactory organs
- Feel presence of others – proprioreceptors and cuticular hairs

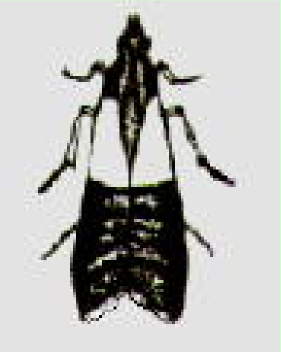
- An acoustic signal is generated by vibrations of a sound-producing organ
- Mechanoreceptive organs perceive the sound

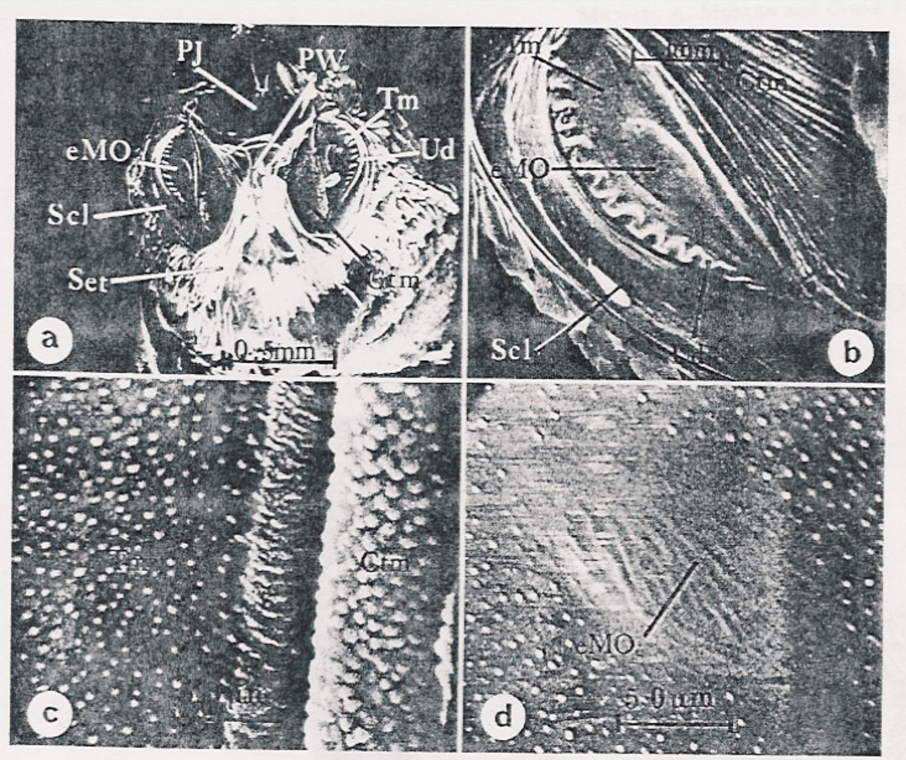
- Near-field acoustic detectors
  - Cerci of cockroaches, Johnston’s organs of mosquitoes, aristae of drosophilid flies
  - Lack eardrums
  - Work short distances (few body lengths in drosophilid flies, 1 m for male mosquitoes)
  - Low frequencies, 75 – 500 Hz
- Far-field acoustic detectors
  - Respond to 2 – 100 kHz
  - Can detect sounds from long distances (10 m or more)
  - Need tympanic organs or eardrums (but not always)
  - Thin region of cuticle with an air-filled sac behind it and a chordotonal sensory organ

Tympanal hearing

- Present in 7 insect orders
- Neuroptera – wing base
- Lepidoptera – Abdomen, metathorax, base of fore or hind wing
- Coleoptera – Cervical membranes, abdomen
- Dictyoptera – Ventral metathorax, Metathoracic leg
- Orthoptera – First abdominal segment, prothoracic leg
- Hemiptera – Abdomen, mesothorax
- Diptera – Ventral pro-sternum

Indian meal moth





a: Anterior view of the tympanic organ

b. Anterior view of the left tympanic organ

c: Division between tympanic membrane proper and countertympanic membrane.

d. Area of external expression of Muller's organ

Tympanic organ of Indian meal moth (Mullen & Tsao 1971)

Insects use ultrasound for several purposes

- Long-distance mate calling (male calls, female responds--in crickets, katydids, grasshoppers, and cicadas)
- Short distance calling song (by mutual antennation in field crickets)
- Rivarly song or territorial proclamation (male-male aggression)
- Predator detection – night flying moths
- Acoustic parasitism – Field crickets and tachinid fly (*Ormea ochracea*), 4 – 6 kHz (host 4.8 kHz). Fly also is sensitive to 20 – 60 kHz sound
- Male and female insects have different auditory sensitivities (Gypsy moth, tachinid flies, cicadas)
    - Intra-specific communication vs prey detection

Auditory capabilities evolved

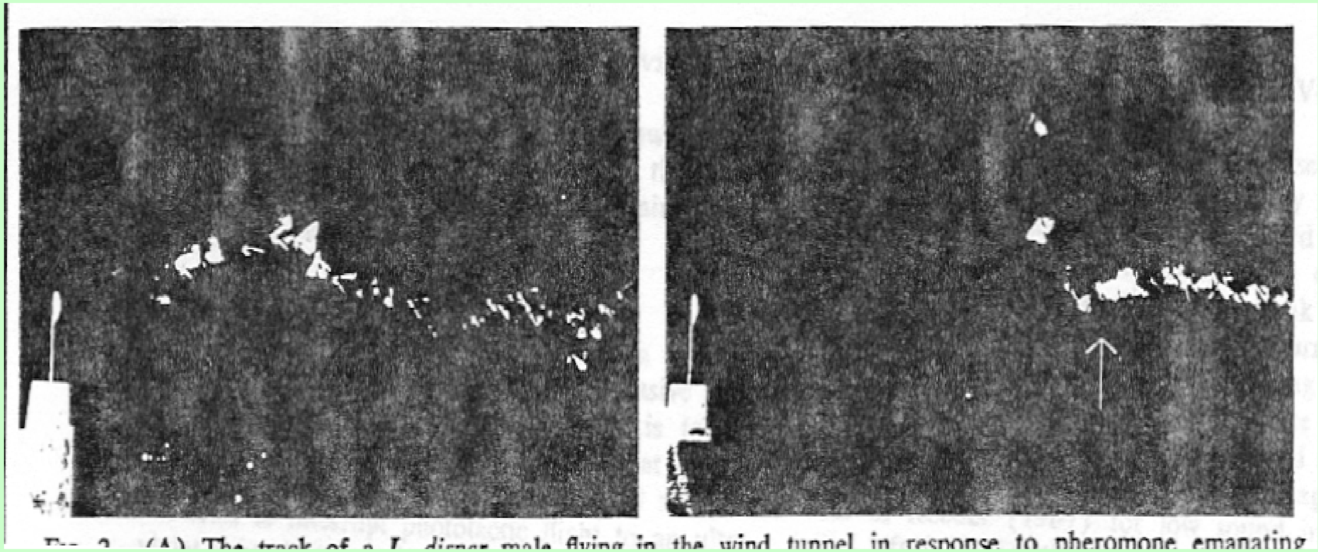
- To facilitate conspecific communication
- To detect predators

- Insect's ability to hear need not be based solely on organs visible on anatomic examination of the body surface
- Only a few species have been studied
- Species that use auditory signals may do it at night or high in the air—a challenge for us to study!

Echolocating bats

- Aerial hawking bats
  - Catch flying insects on the wing
  - Use sonar to target and capture prey
  - Prefer open habitats
  - Produce low frequency, high intensity, long duration pulses
- Substrate gleaning bats
  - Forage near the ground or surrounding vegetation
  - Use sonar as a navigational tool to avoid obstacles
  - Prefer “closed” habitats
  - Produce high frequency, low intensity, short duration pulses
  - Acoustically less “conspicuous” to eared insects

Evasive maneuvers by Gypsy moth males



- Left: The tracks of a gypsy moth male flying in the wind tunnel in response to pheromone emanating from the pheromone disperser. No auditory stimulus was given.
- Right: The tracks of a pheromone responding male in the wind tunnel when the auditory stimulus was given (arrow) from outside the wind tunnel causing the male to abruptly change course and fly out of the plume (Baker & Cardé 1978)

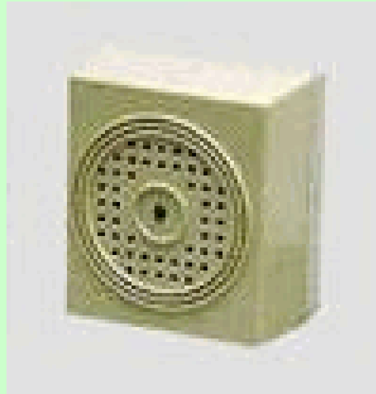
Ultrasonic devices and pest control

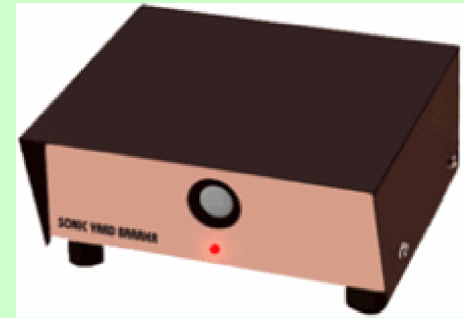
United States ultrasound market

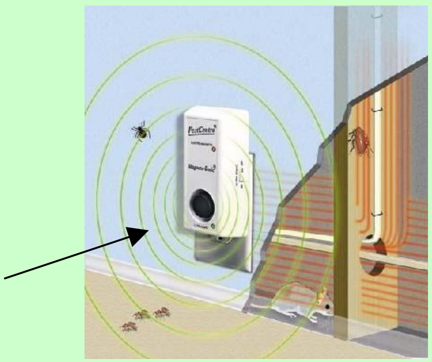
- More than 60 manufacturers and retailers

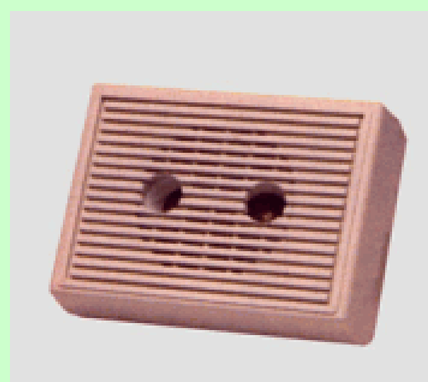
- Estimated market value may be around 100 million
  - One US company alone has $20 million in sales annually

Range of available ultrasonic devices marketed in the United States







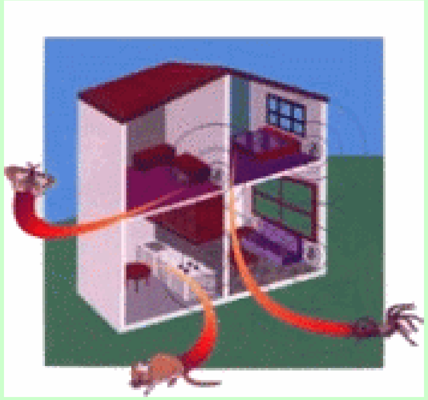


Manufacturers and retailers claim that pests can be repelled by ultrasonic devices!

Target pests

Rats, mice, squirrels, mosquitoes, ants, spiders, cockroaches, flies, fleas, ticks, crickets, yellow jackets, bees, moths, water bugs, silverfish …

Preposterous claims by manufacturers and retailers



- Gets rid of household pests without chemicals or poisons
- Our safe Electronic Pest Repellers and Flea Collars use high frequency sound to drive away pests
- Millions of satisfied users report that these products safely chase away fleas, mice, rats, squirrels and other rodents, as well as roaches, moths, ants, spiders, mosquitoes, and many other creepy pests

Source: http://www.hitecpet.com/pestcontrol.html

The DX-610 electronic pest control repeller

- Drives away mice and rats, fleas, spiders, **bats**, ants, cockroaches, moths, water bugs, silverfish, and most other common pests
- Covers 2,000-2,500 square feet
- Environments: Homes, but also in their garages, offices, warehouses, campers, restaurants, schools, and barns
- Marketing: Over 23 countries, including Japan, Australia, Greece, Spain, Brazil, Denmark, Mexico, and Canada

Testimonials

"...could hear the mice running around at night. Well, now they are gone. This product really worked!" ---- Bob G. from Massachusetts

"...I can't believe how good it works. FIRST CLASS PRODUCT!" … Joe J from Nevada

- Source: http://www.msglobaldirect.com/html/electronic_pest_control.html

Published research results

Most tests measured repellent effects

Field and laboratory efficacy tests with ultrasonic devices

Pests	Authors	Test conditions	Frequency, kHz	SPL dB at distance, cm	Effective	S/F
Flea	Brown & Lewis, 1991	Chamber	--	--	no	0/4
	Dryden et. al., 1989	Cage	40	80-92 at 100	no	0/2
	Dryden & Gaafar, 1991	Cage	40-50	--	no	0/1
	Dryden et al. 2000	Cage	--	--	no	0/1
	Hinkle & Koehler, 1990	Cage	35, 39, 41	102 at 5 84 at 50	no	0/1
	Koehler et al., 1989	Lab	40	82 at 50 76 at 100	no	0/1
	Schein et al., 1988	Lab	--	--	no	0/1
	Rust & Parker, 1988	Lab	1 – 200 40, 50	--	no	0/1
	Koehler et al., 1986	Room Chamber	17 - 61	51 – 103 at 100	no	0/9
Summary of successes (S)/failures (F): 0/21						

Pests	Authors	Test conditions	Frequency, kHz	SPL dB at distance, cm	Effective	S/F
Cockroach	Brown & Lewis, 1991	Chamber	--	--	no	0/4
	Ballard & Gold, 1983	Chamber	20-60	--	?	6/18
	Ballard et al., 1984	Chamber	30-65	60-68.5 at 200	yes	4/4
	Gold et al., 1984	Chamber	40, 20-50	70-110 at 91	?	3/4
	Koehler et al., 1986	Room Chamber	17 - 61	51 – 103 at 100	no	0/9
	Koehler et al., 1989	Lab	40	82 at 50 76 at 100	no	0/1
	Schreck et al., 1984	Chamber	1: 44, 53 2: 30-35, 43	1: 65 at 50 2: 96 at 0.5	no	0/2
	Summary of the successes (S)/failures (F): 13/42					
Tick	Brown & Lewis, 1991	Chamber	--	--	no	0/4
	Schein et al., 1988	Lab	--	--	no	0/1
	Summary of the successes (S)/failures (F): 0/5					

Some field or laboratory efficacy tests of ultrasound to repel insects

Pests	Authors	Test conditions	Frequency kHz	SPL dB at distance cm	Effective	Ratio
Mosquito	Gorham, 1974	--	--	--	no	0/1
	Kutz, 1974	--	--	--	no	0/1
	Garcia et al., 1976	Lab and field	--	--	no	0/1
Mosquito	Schreck et al., 1984	Chamber	1: 44, 53 2: 30-35, 43	1: 65 at 50 2: 96 at 0.5	no	0/2
	Schreiber et al., 1991	Chamber and field	-	-	no	0/5
	Sylla et al., 2000	Houses	3-11	--	no	0/4
	Summary of the successes (S)/failures (F): 0/14					
European corn borer	Belton & Kempster, 1962	Corn field	50	100 at 30	yes	1/1, 50% Rd
	Agee & Webb, 1969	Light traps	20, 25, 30	100 at 100	yes	1/1, Rd by 81%
Cabbage looper	Payne & Shorey, 1968	Lettuce and broccoli fields	20, 30 40	---	yes	2/3, Rd up to 66%
Bollworm	Agee & Webb, 1969	Cotton field	20, 25, 30	100 at 100	no	0/1
	Shorey et al., 1972	Corn field	20	60-105 at 25,00-0	no	0/1
	Agee & Webb, 1969	Light traps	20, 25, 30	100 at 100	yes	1/1 Rd by 75%
Summary of the successes (S)/failures (F): Moth= 5/8; Overall=18/90						

2001 FTC Warns Manufacturers and Retailers of Ultrasonic Pest Control Devices

- **Efficacy claims about these products must be supported by scientific evidence**
- **FTC challenged the following types of claims:**

-- Eliminates rodent infestations

-- Repels insects

-- Serves as an effective alternative to conventional pest control products

-- Increases or assists the effectiveness of other pest control methods

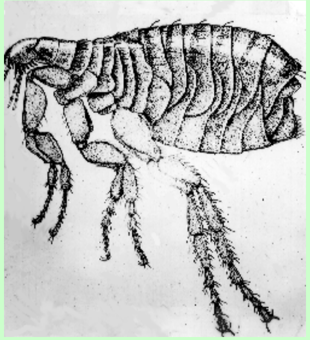
-- Eliminates fleas on dogs or cats

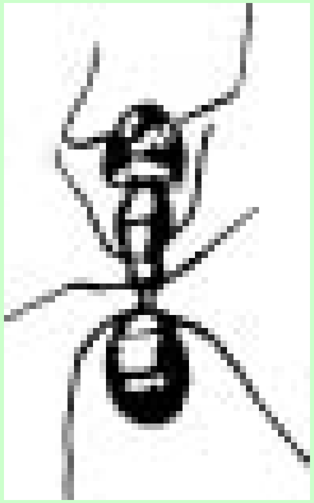
Source: http://www.ftc.gov/opa/2001/05/fyi0128.htm

Kansas State University (KSU) test results with ultrasonic devices against arthropod pests (2000-2003)

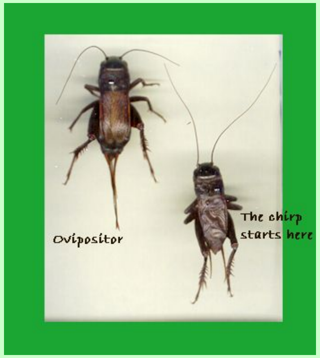
- 5 commercial devices: A, B, C, D, and E
- 1 random ultrasound-generating unit (developed at KSU)
- 9 groups of arthropod pests

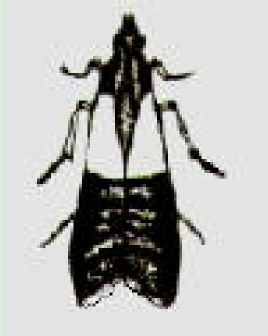
Arthropods used in tests





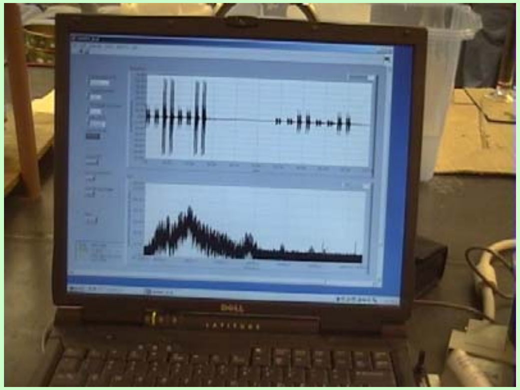

- Cat fleas, *Ctenocephalides felis*
- German cockroach, *Blattella germanica*
- Ants, *Camponotus festintatus*, *C. pennsylvanicus*, *Formica pallidefulva*
- Eastern yellow jacket, *Vespula maculifrons*





- Long-bodied cellar spiders, *Pholcus phalangioides*.
- Field and house crickets, *Acheta assimilis, A. domestica*
- Fly complex: Green bottle fly (*Phormia* spp.), flesh fly (Sarcophagidae), house fly (*Musca domestica*), blow fly, and 2 other unknown fly species
- Imperil scorpion, *Pandinus imperator*
- Indian meal moth, *Plodia interpunctella*.

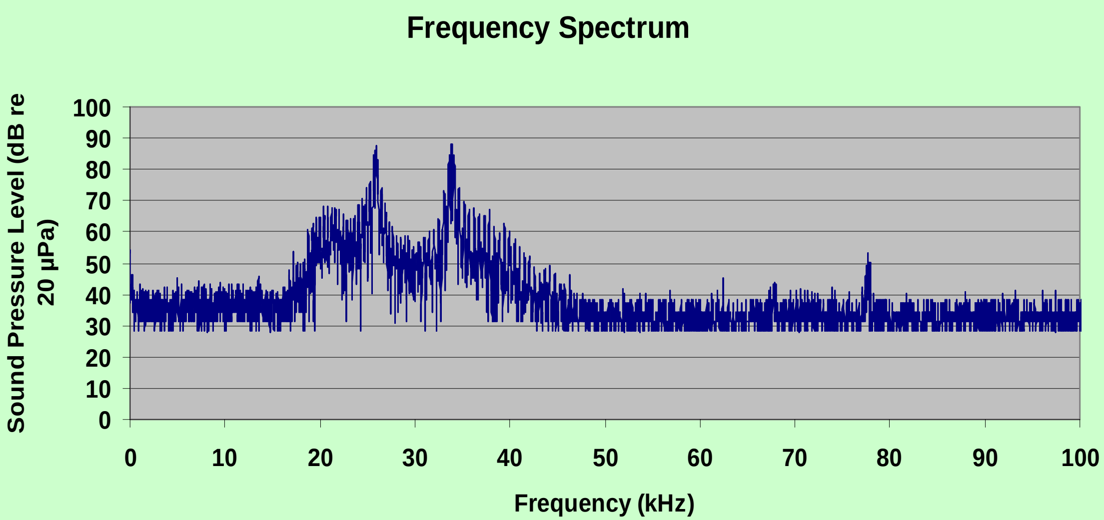
Sound characterization



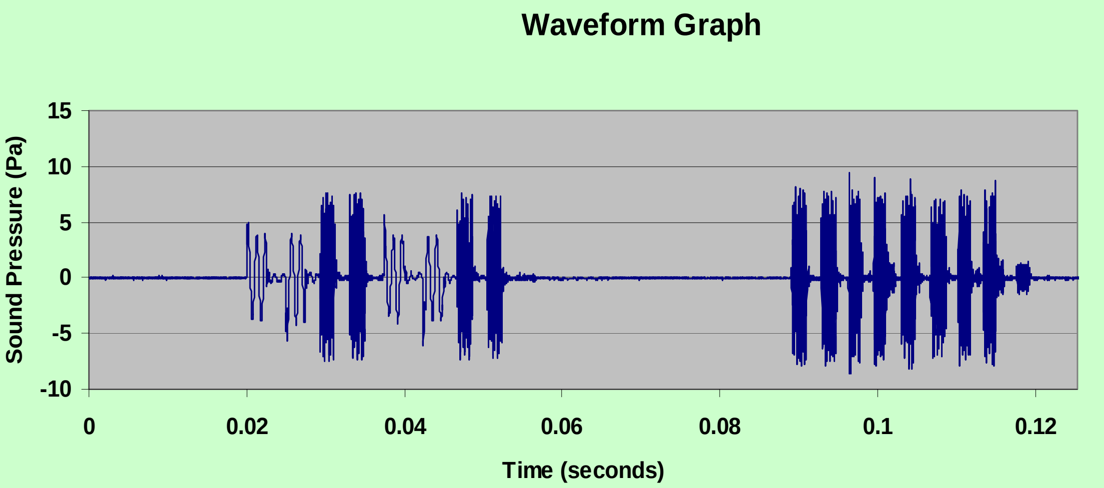
• Bruel and Kjaer (B&K) type 4939 condenser microphone, B&K type 2670 preamplifier, and B&K NEXUS conditioning amplifier

• Measurements were made at a distance of 50 cm. Units A: 11 devices, B: 11, C:14, C: 3, D: 2, and E: 2 devices

Sound characterization, Device A (Mode A & Quiet)

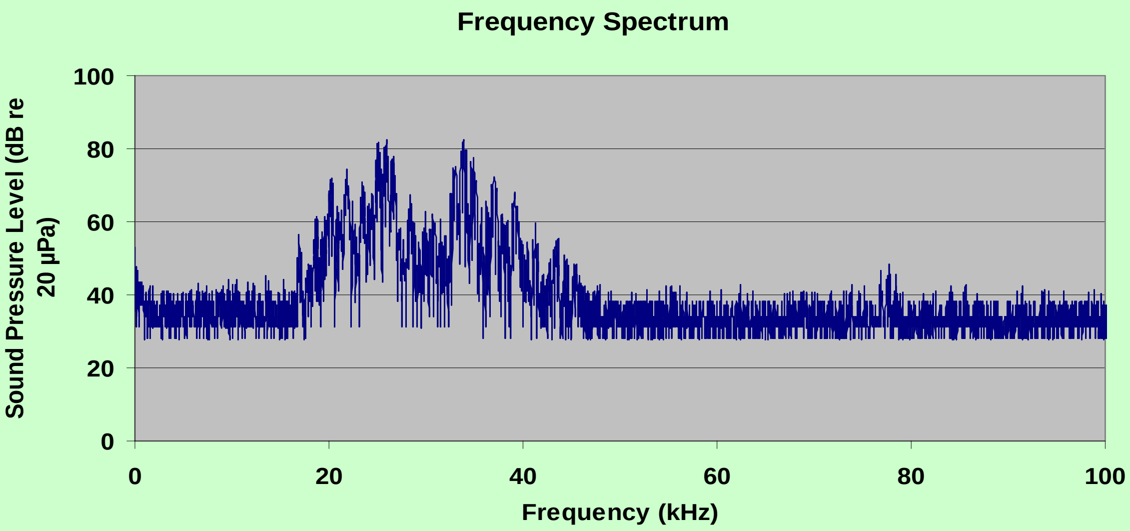


- 26 and 34 kHz
- SPL = 95 ± 1 dB at 50 cm

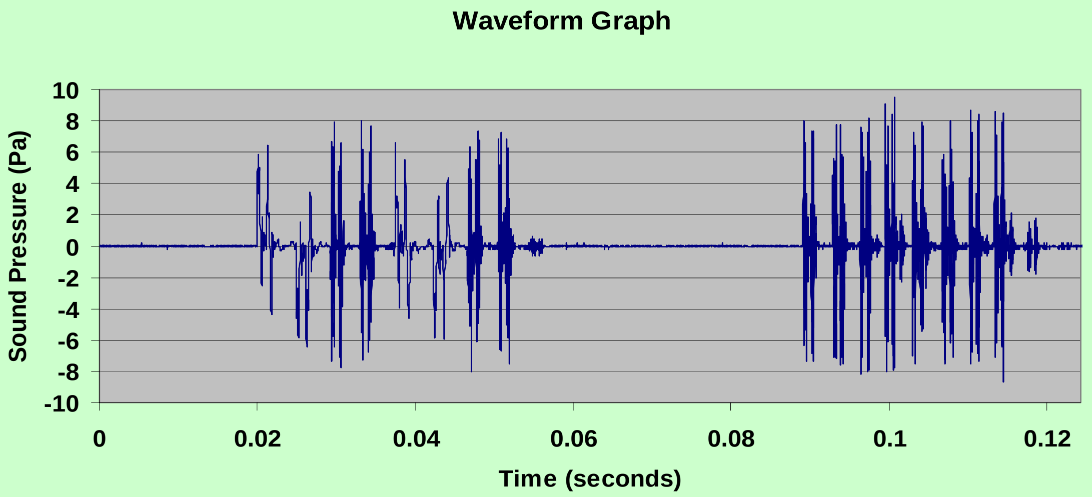


- 0.123 second of one cycle.
- 2 groups of pulses with 8 pulses in each group

Sound characterization, Device A (Mode B & Quiet)

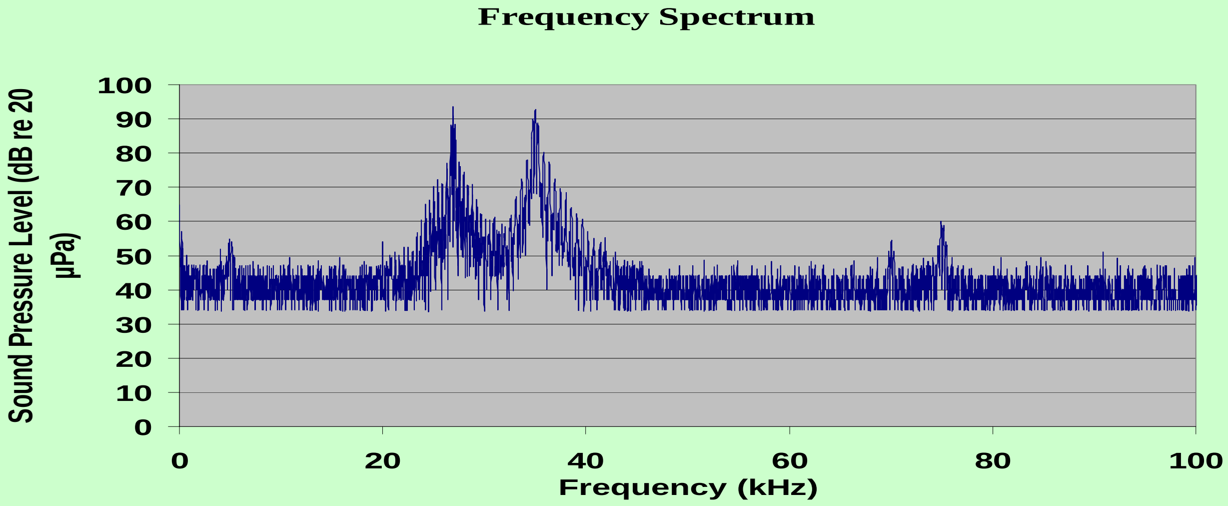


- 21 kHz, 35 kHz, and 41 kHz
- SPL = 94 dB (SPL) at 50 cm distance

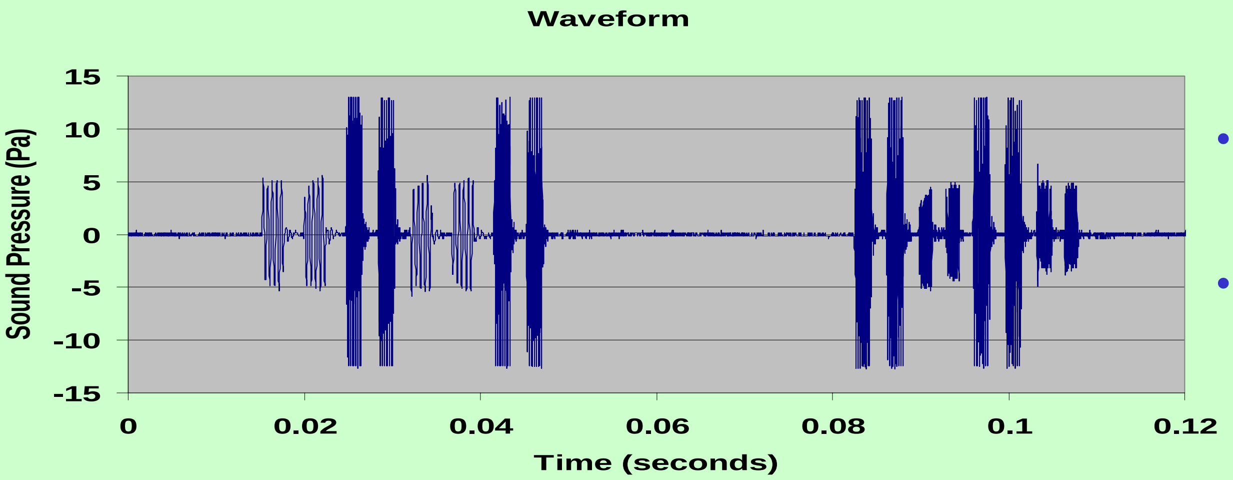


- 0.123 second of one cycle of the sound
- 2 groups of pulses with 8 pulses in each group

Sound characterization, Device B

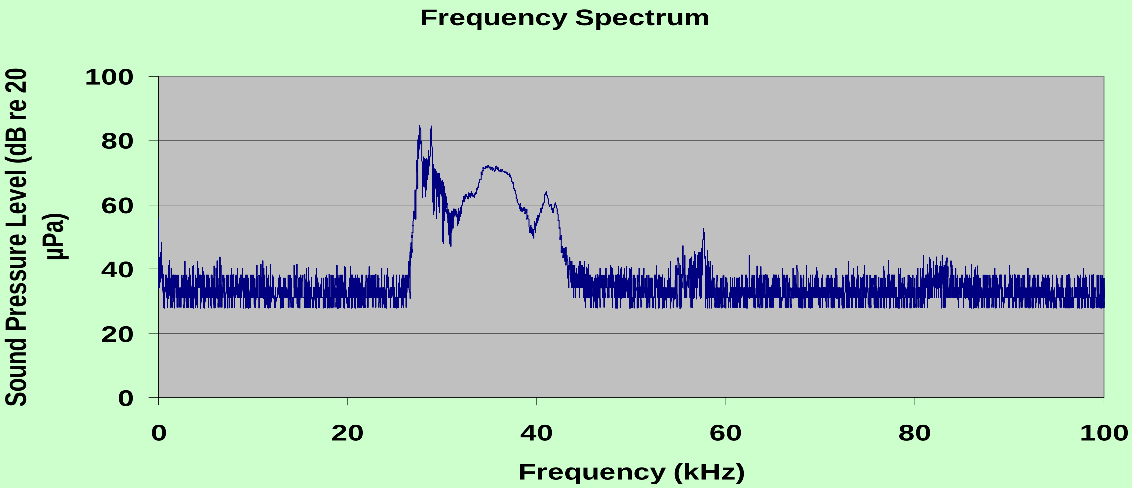


- 27 and 35 kHz
- SPL = 92 ± 4 dB

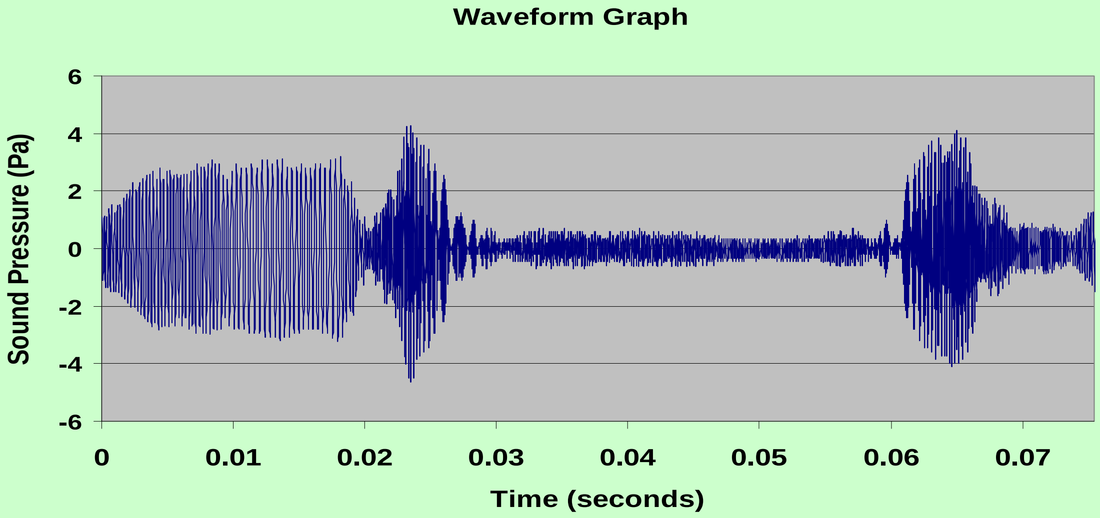


- 0.123 second for one sound cycle
- 2 groups of pulses with 8 pulses in each group

Sound characterization, Device C

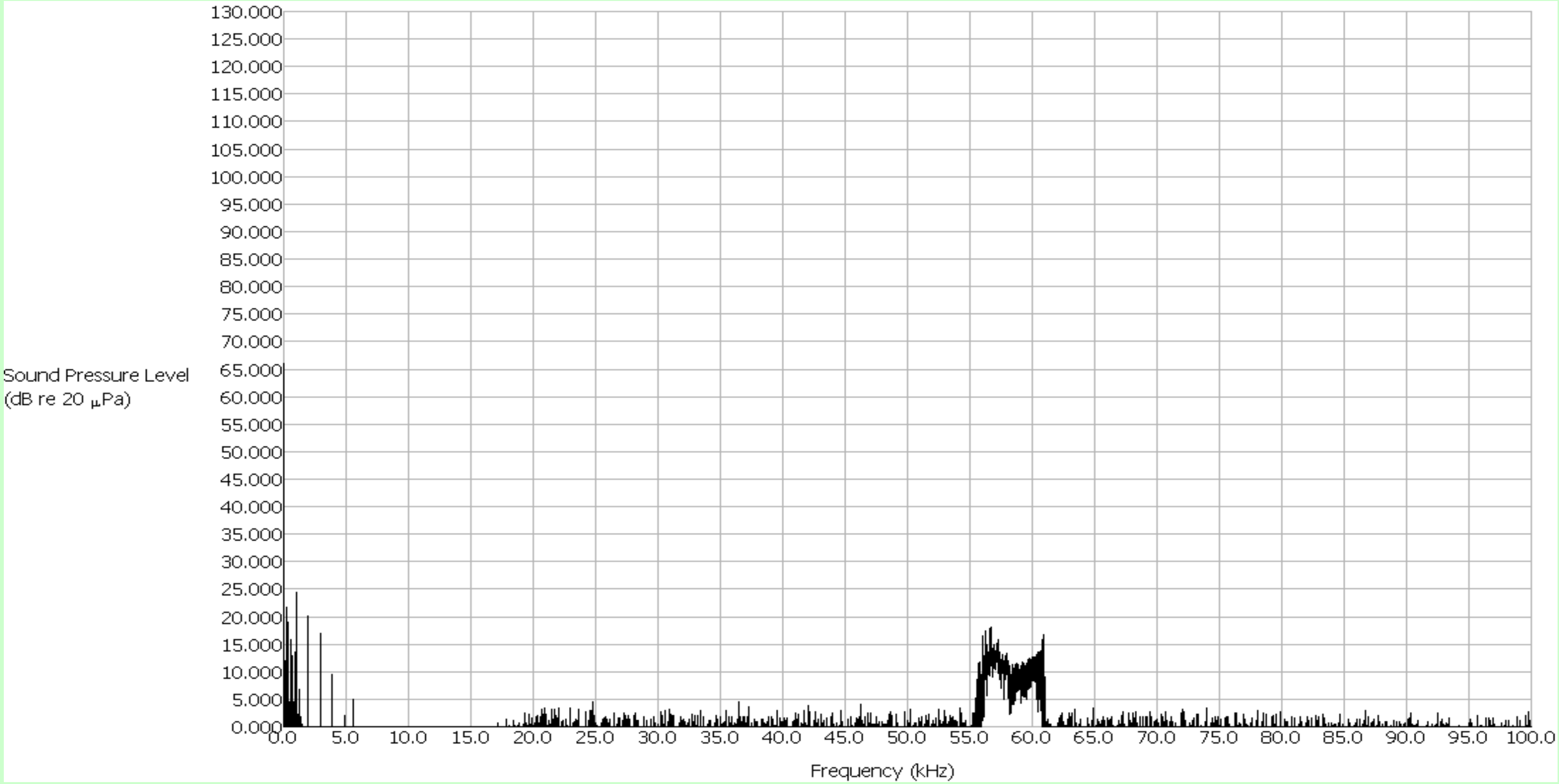


- A wide range of peak frequencies between 27.7 to 42 kHz
- SPL = 88 ± 2 dB at 50 cm



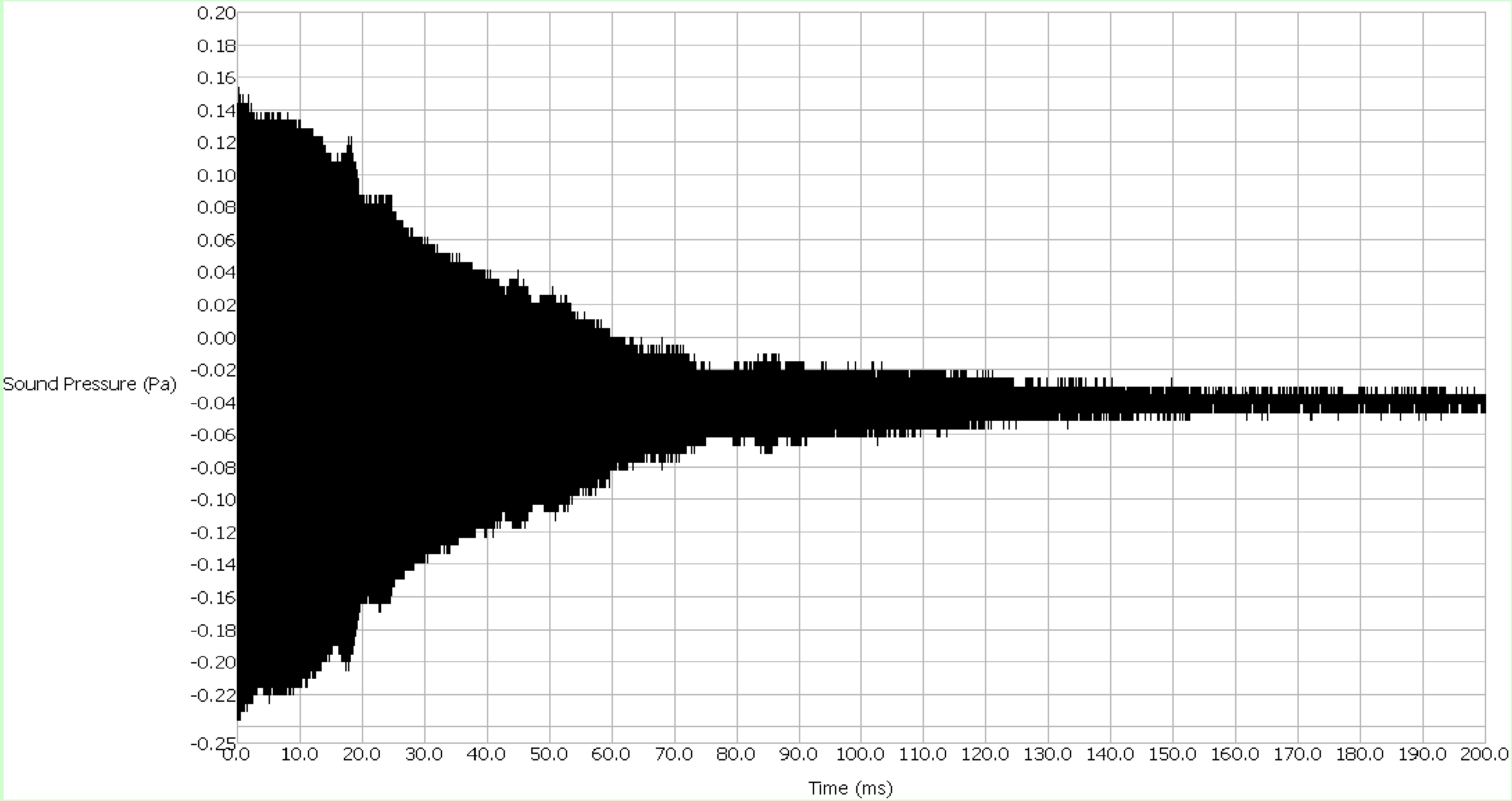
- 0.075 second in duration
- 3 groups of pulses, and each group was characterized by multiple pulses

Sound characterization, Device D (Frequency)



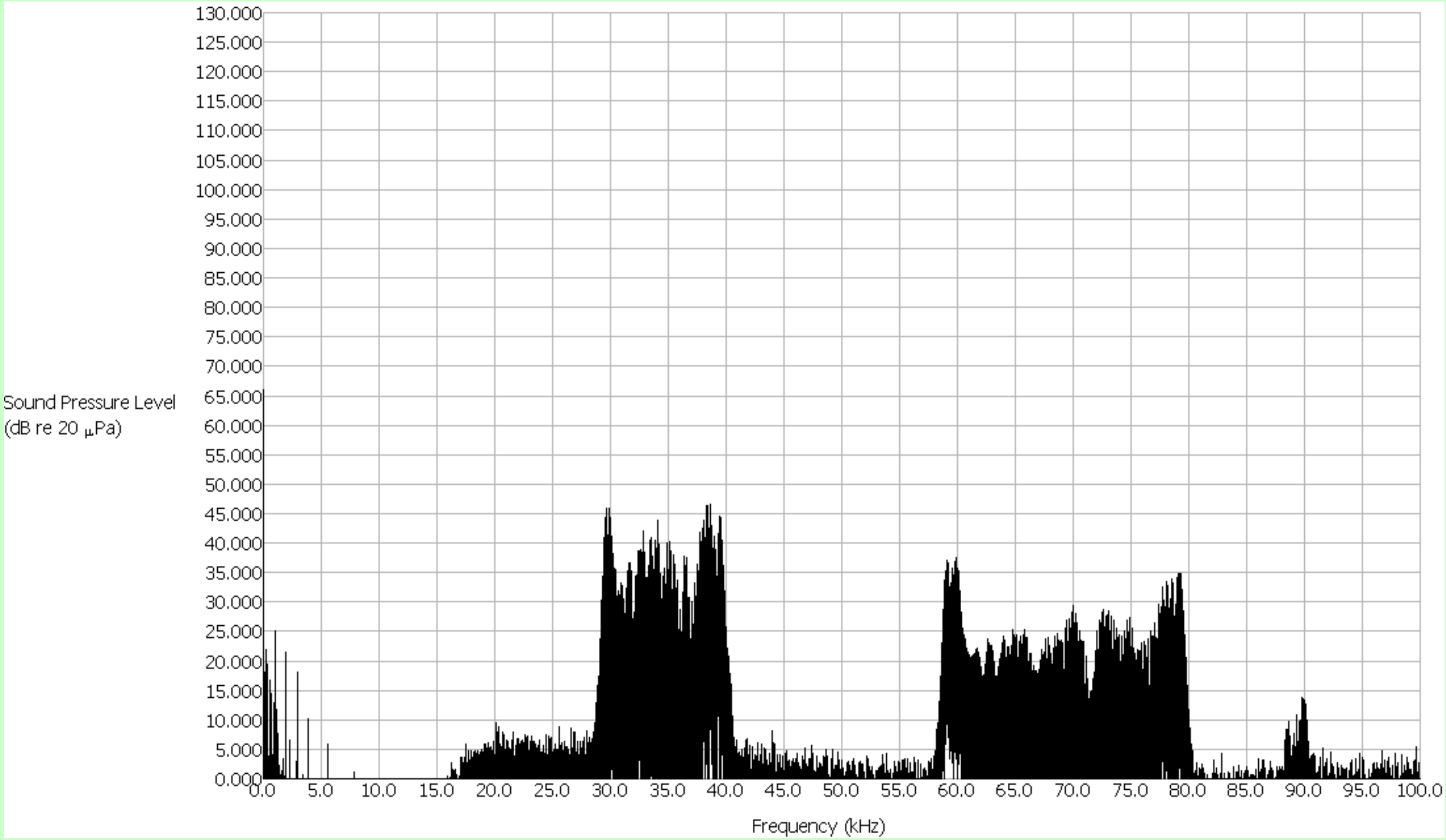
- Small peak at 50-60 kHz
- SPL = 70 dB sound pressure level at 50 cm

Sound characterization, Device D (Waveform)



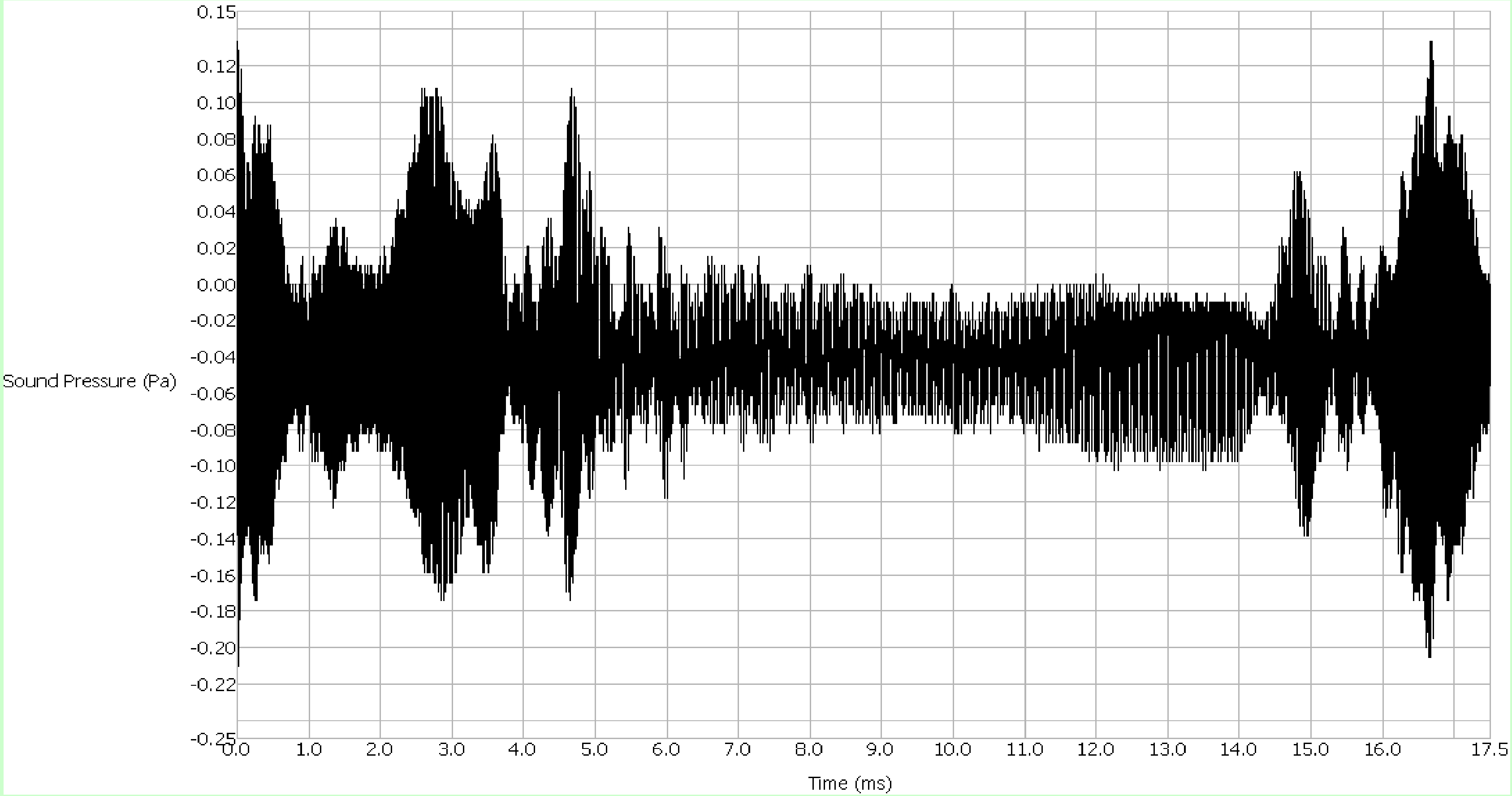
- Several different sound waveform patterns
- at least 3 distinct sound patterns

Sound characterization, Device E (Frequency)



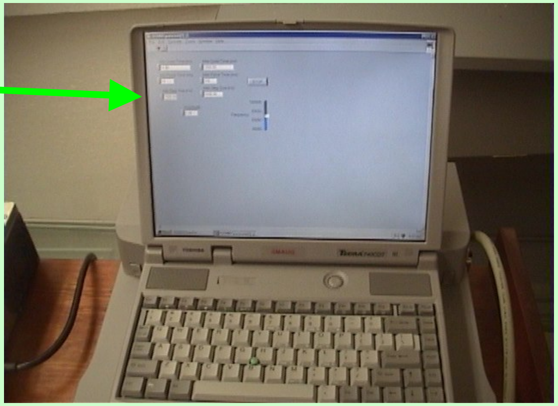
- **Peak frequencies at 26 to 40 kHz and at 60 to 80 kHz, plus a small peak frequency at 90 kHz**
- **SPL = 70 dB at 50 cm**

Sound characterization, Device E (Waveform)



- 0.017 second of one cycle of the sound
- 4 -5 groups of pulses with many pulses in each group

KSU random-ultrasound generating system

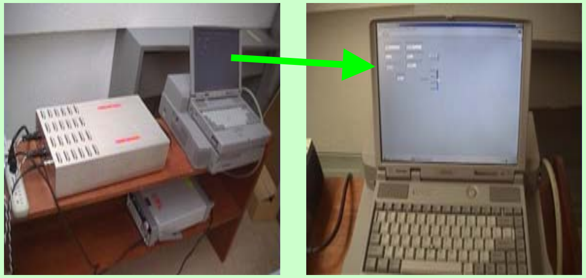


- an ultrasound generator (left)
- a computer (right) with electrostatic amplifier
- sound frequencies, pulse repetition rates, and quiet time at random

- **Sound parameter settings:**

-- Min Quiet Time (ms): 50
-- Max Quiet Time (ms): 300
-- Min Pulse Time (ms): 50
-- Max Pulse Time (ms): 200
-- Min number of pulses: 7
-- Max number of pulses: 15
-- Amplitude: 2.25
-- Feeding buzz control: 100
-- Frequency: 20 – 80 kHz

KSU random-ultrasound generating system



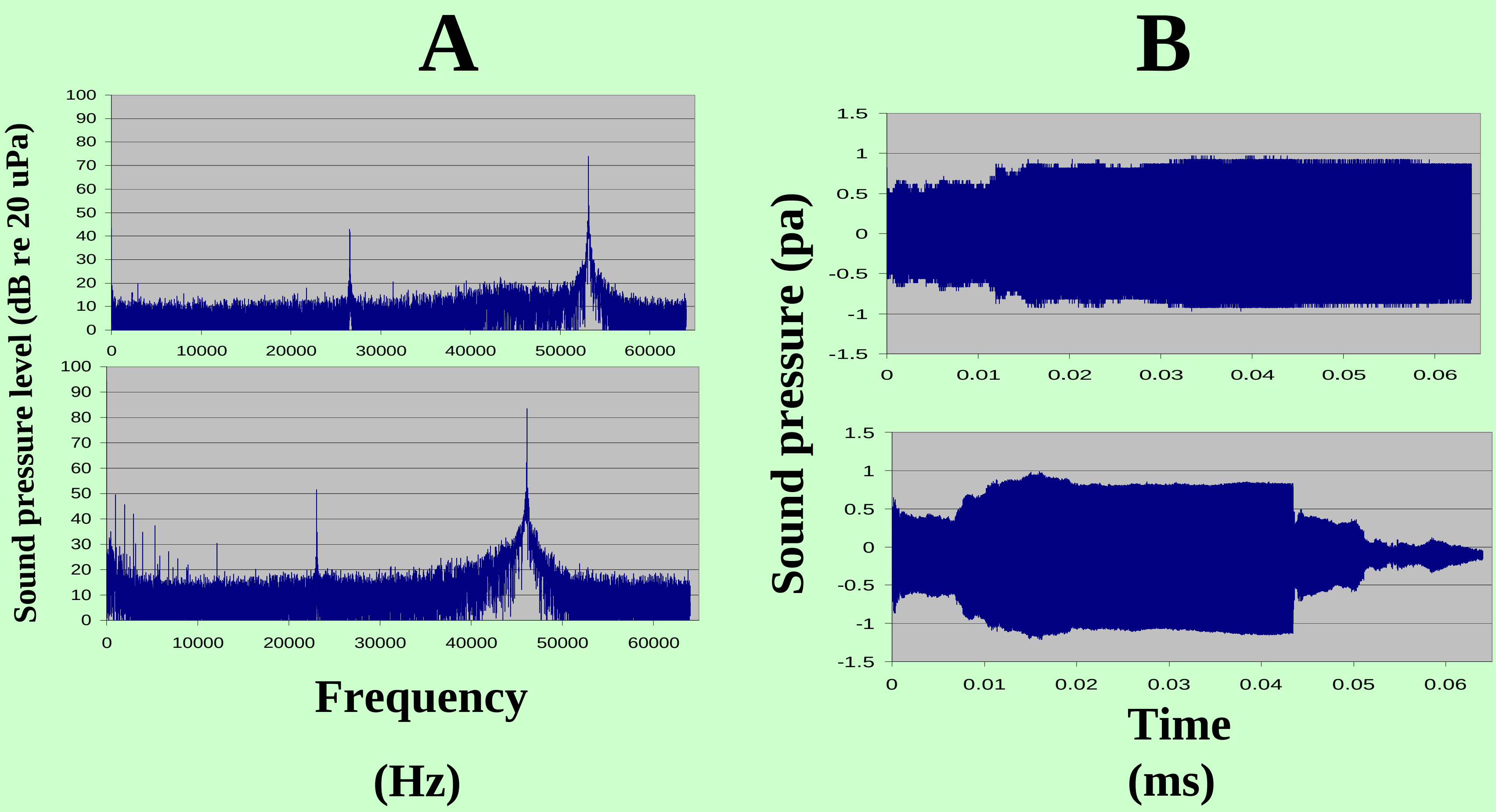
- The computer randomly chooses the pulse length, frequency (20 to 100 kHz), and quiet time between pulses across the entire frequency range

- One device can drive two ultrasonic emitters simultaneously

- The ultrasonic emitter, on average, produced 95dB at the bottom center of the enclosure

- A laptop computer to characterize the output of the ultrasonic emitter

KSU random-ultrasound generating system



Sound frequency spectrum (A) and waveform graph (B) produced by the KSU ultrasonic generator. The figures show change in sound frequencies and waveforms over time

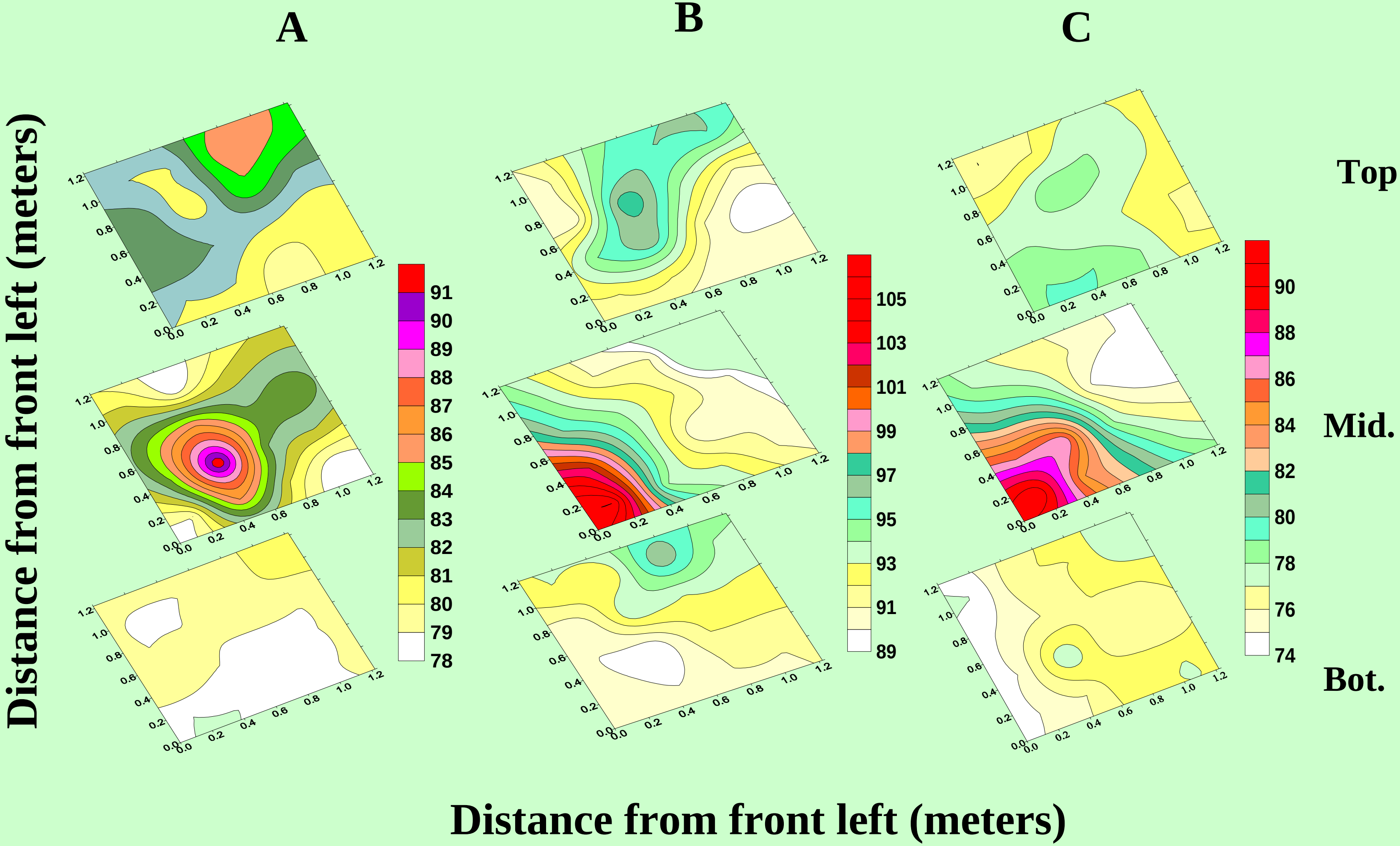
Measurement of sound output inside test enclosures

Test enclosures

- 8 Plexiglas enclosures, 4 x 4 x 4 ft
- A 2–3 feet long square conduit (3 x 3 x 3 in)
- All sides of each enclosure were divided into 16 equal quadrats
- An unit was mounted on the top corner, diagonally opposite from the conduit openings, or on the center of the top surface and faced the center of the bottom surface of an enclosure
- Sound pressure level (dB) within an enclosure at the bottom, middle, and top levels for the ultrasonic devices A, B, and C were measured

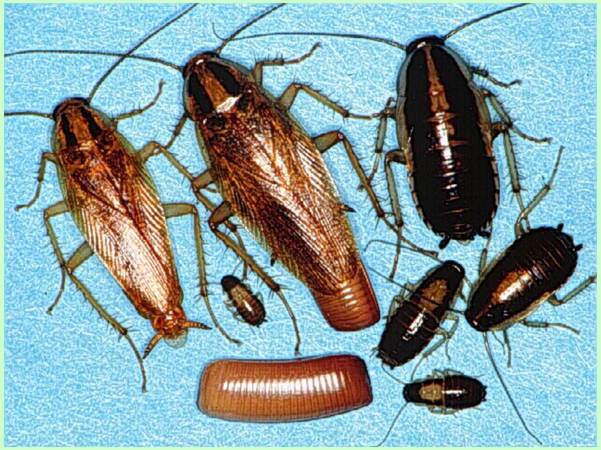
Sound pressure level (dB) within an enclosure at the bottom, middle, and top levels for the ultrasonic devices A, B, and C

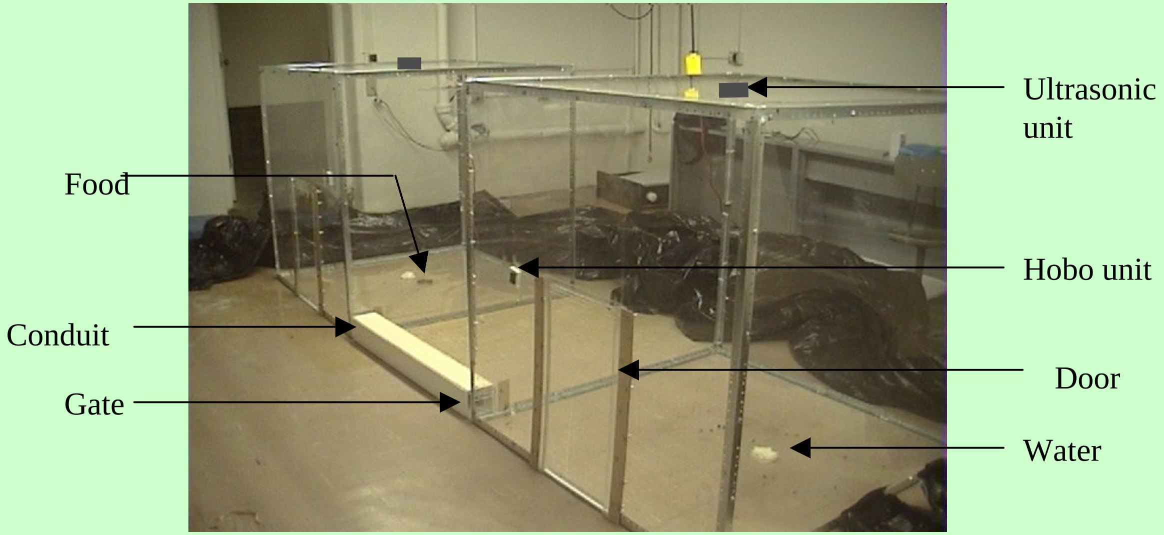
Device	Bottom	Middle	Top
A	77-80	89-97	74-79
B	78-84	89-96	76-80
C	78-86	89-106	74-91



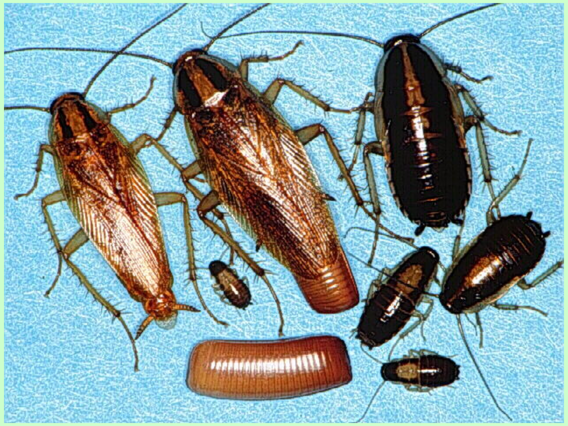
Contour maps showing distribution of sound pressure levels within an enclosure at the bottom, middle, and top levels for the ultrasonic devices A, B, and C. The device position within an enclosure was at (0,0) coordinates near the top

Cockroach tests

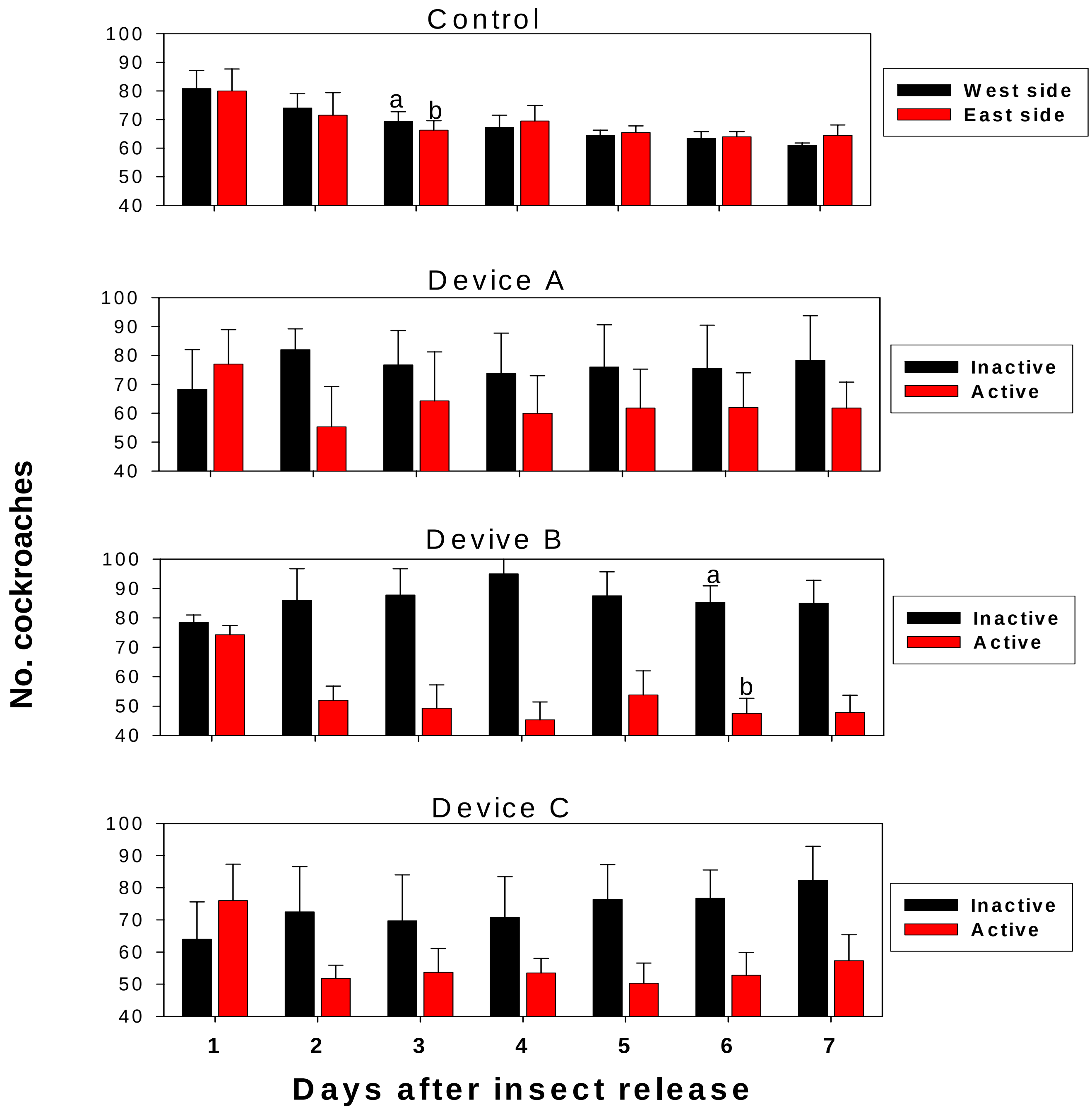




- German cockroach
- Ultrasonic devices A, B, and C
- 100 insects/enclosure
- Number of cockroaches was counted each day
- 7-days for each test (replicate)
- 4 tests for each device and control
- Data on the number of cockroaches were analyzed by paired *t*-tests



Day	Action		# of insects	
	A	B	A	B
0	Start	Start	100	100
1	off	off	xxx	xxx
2	on	off	xxx	xxx
3	on	off	xxx	xxx
4	on	off	xxx	xxx
5	on	off	xxx	xxx
6	on	off	xxx	xxx
7	on	off	xxx	xxx


Control
West side
East side
a
b
Device A
Inactive
Active
Devive B
Inactive
Active
a
b
Device C
Inactive
Active
No. cockroaches
100
90
80
70
60
50
40
1
2
3
4
5
6
7
Days after insect release

Conclusions

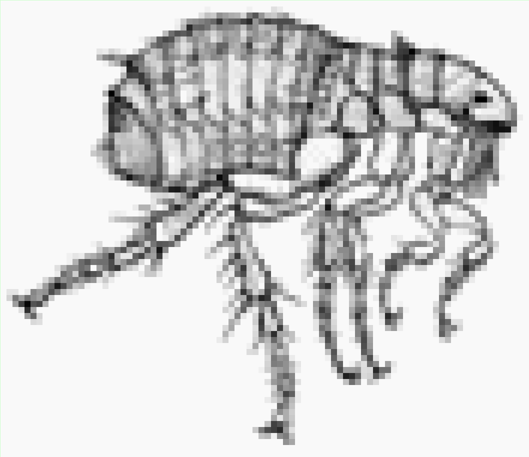
- The number of cockroaches in the enclosures with active ultrasonic units were consistently lower than those found in the enclosures with inactive units for all three devices throughout the test period

- Paired *t*-tests indicated that differences in cockroach numbers were not statistically significant ($P > 0.05$)

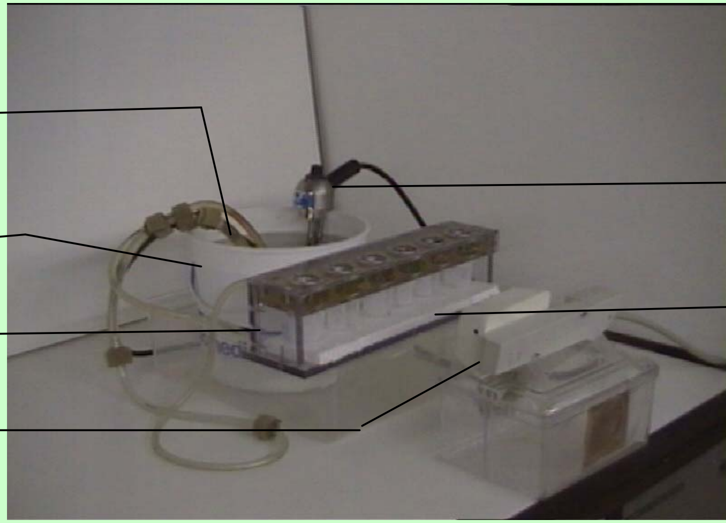
- Ultrasound produced from the devices had a marginal effect in repelling cockroaches

- The level of repellency observed may not be of commercial significance

Cat flea tests



- It is the most important ectoparasite of companion animals such as cats and dogs



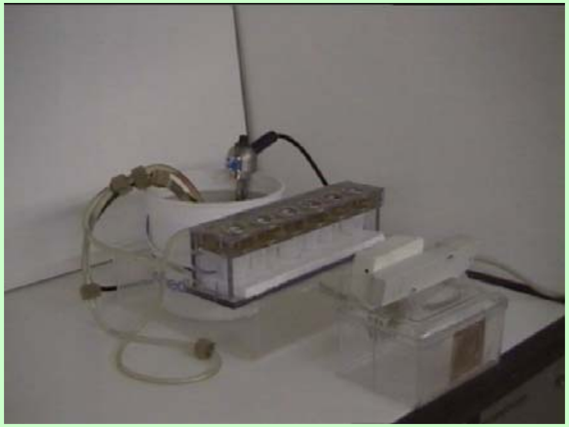
Artificial flea feeding device

- Artificial flea blood feeding device

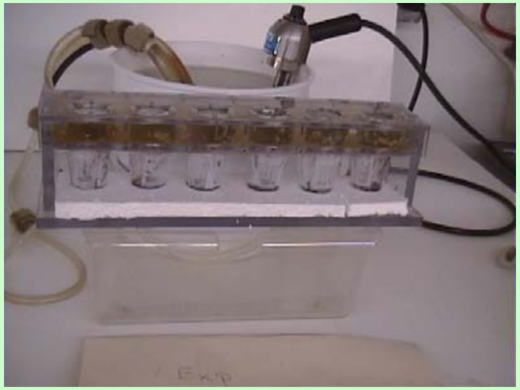
- 6 flea feeding sleeves

- Six 30 ml-plastic cups held the fleas
- Three windows (ca 25 x 15 mm each) were cut around the well of each cup.
- These openings were sealed with a 400-mesh nylon screen to allow ultrasonic pulses to pass through
- Cups were then fitted to the feeding device

- One end of the feeding sleeve was sealed with parafilm
- 3 ml ox blood was put into each sleeve
- The sleeves with blood were put into the holes of the artificial feeding stage
- The fleas inside the cups were able to imbibe blood from the sleeves through the screens and parafilm

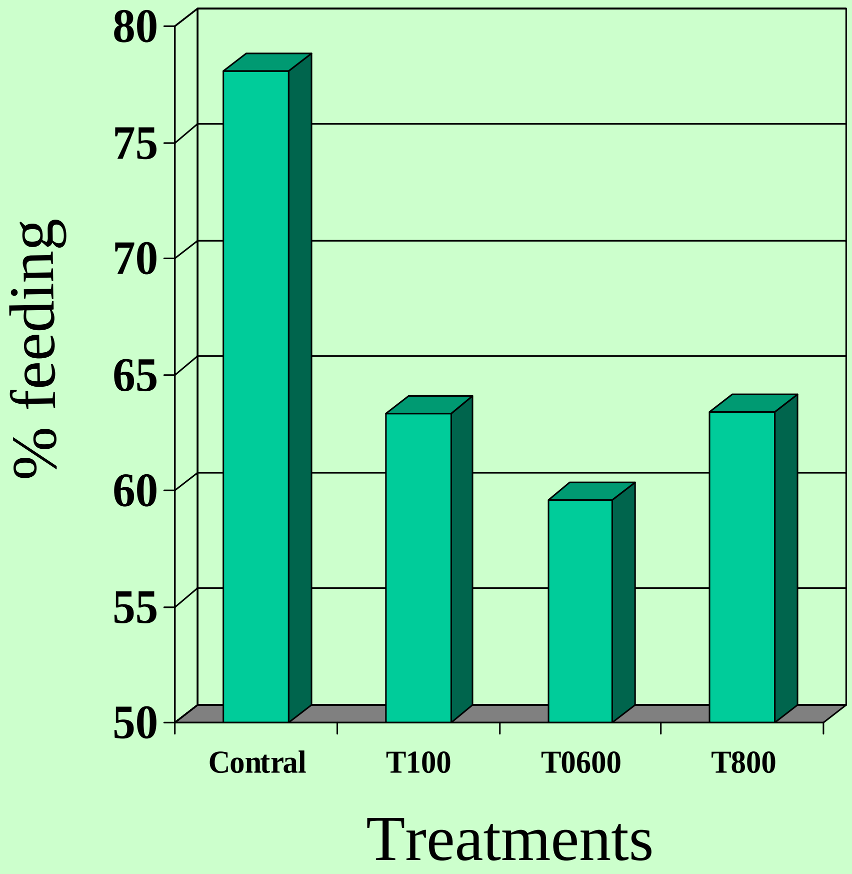


- Blood was maintained at 39^{o}C through a temperature controllable water circulation system
- The blood was changed every two days
- Each test was run for four days



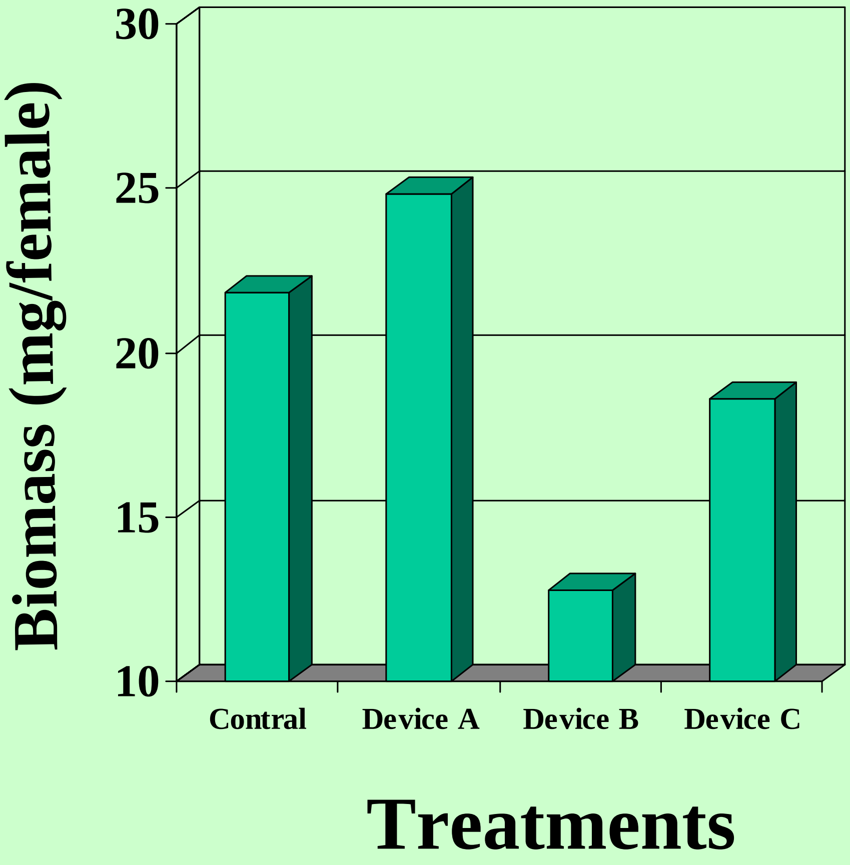
- 9 tests: 2 for control, 2 for device A, 4 for device B, and 1 for device C
- Number of fleas feeding in each cup was counted twice daily
- Biomass (feces + flea bodies + eggs) in each cup was weighed
- Number of eggs in each cup was counted

Number of fleas feeding

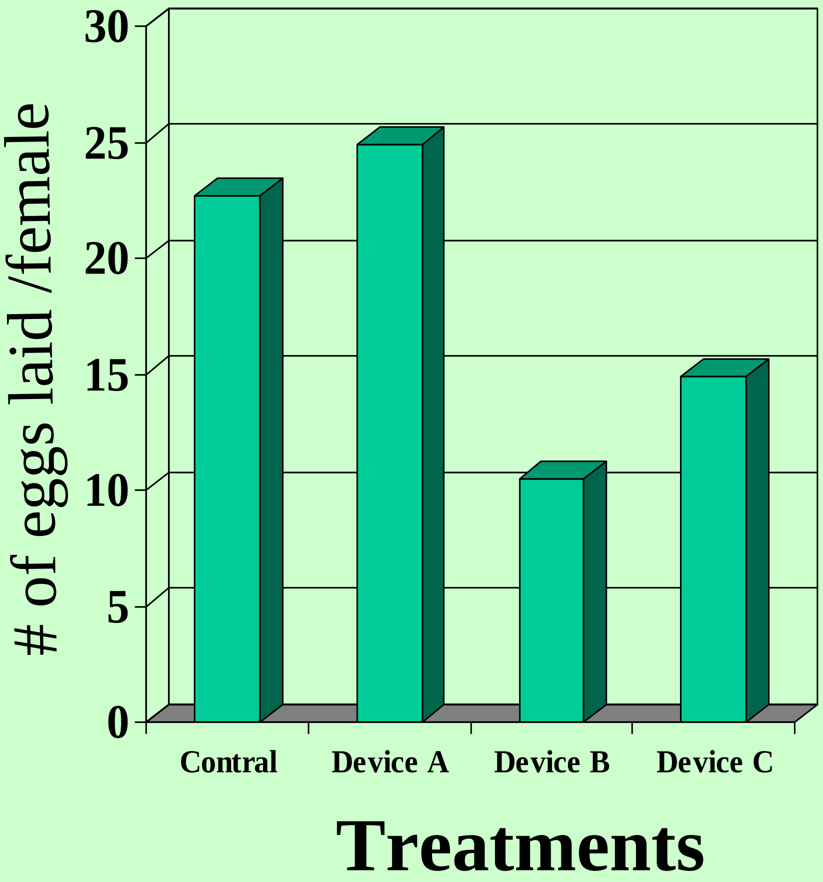


- **Control: 78%**
- **Treated: 62%**

Biomass (mg/female)



- **Control: 22**
- **Device A: 25**
- **Device B: 13**
- **Device C: 19**



Egg laying (eggs/female)

- **Control: 23**
- **Device A: 25**
- **Device B: 11**
- **Device C: 15**

Conclusions

- Ultrasonic pulses from device B impacted feeding behavior and reproduction of the cat flea
- No effect from device A
- No clear results for device C (not adequately replicated)

Spider Tests

- House room tests
- Greenhouse tests
- Enclosure tests

House room tests

- Devices A, B, C, and a control
- 20 rooms
- A Pherocon 1C sticky trap was placed on the floor
- An ultrasonic unit was set facing the trap, about 2 ft away
- 5 replications
- Number of spiders were checked 5 times

Number of long-bodied cellar spiders captured per trap and the LSD comparisons

Treatments	# of spiders ± SE*
Control	4.2 ± 0.49 a
Device A	2.8 ± 0.80 ab
Device B	1.4 ± 0.40 b
Device C	1.6 ± 0.68 b

***Values with same letter were not significantly different at the 5% significant level**

- About 90% of the spiders captured were long-bodied cellar spiders
- Number of spiders captured with device B and C units was significantly less than the captures from control rooms
- Devices B and C may repel spiders
- Repellent ability of device A was not significant
- Trap captures were low!

Greenhouse paired tests

- Paired design
- 9 greenhouse rooms (208 – 625 ft^2)
- In each room, two sticky traps were placed at the two corners of the room (pair)
- An ultrasonic unit was set facing 1 ft away from each sticky trap

- Number of spiders were checked at biweekly intervals
- The sticky traps were replaced after each observation

Total number of spiders captured in each spot and the *t*-test results

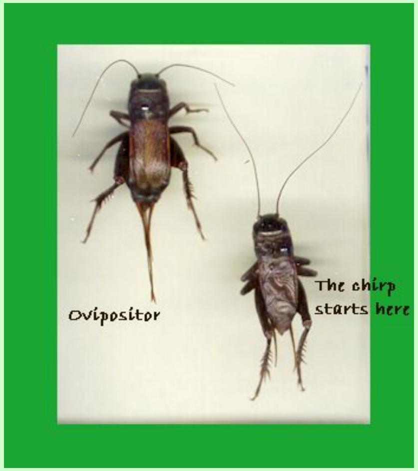
Treatments	# of spiders ± MSE	difference	*t*-value	*P*-value
Control	2.00 ± 0.00			
Device A	1.67 ± 0.88	0.33 ± 0.88	0.3780	0.7418
Control	2.00 ± 0.58			
Device B	2.67 ± 1.45	-0.67 ± 1.33	-0.5000	0.6667
Control	4.00 ± 0.58			
Device C	1.00 ± 0.58	3.00 ± 0.58	5.1962	0.0351

Enclosure tests

- Long-boded cellar spiders from Carolina supplies
- Devices A and C
- Same procedure as used in the cockroach tests
- 15 spiders/pair of enclosures
- 3 paired tests/device

The movements of the spiders was not affected by the ultrasound emitted from any of the tested devices

Cricket tests



- Field cricket and house crickets
- Greenhouse tests, similar to spider tests
- Enclosure tests, similar to cockroach tests

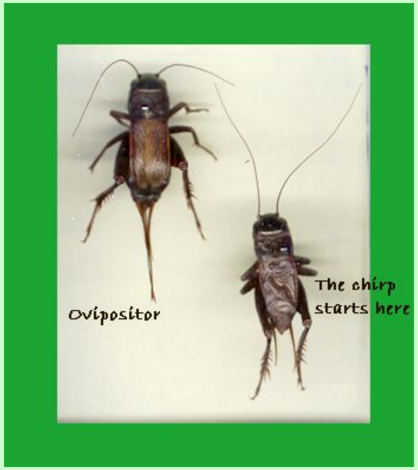
Greenhouse tests

- The ultrasonic units did not repel the field cricket under the greenhouse test conditions

Enclosure tests

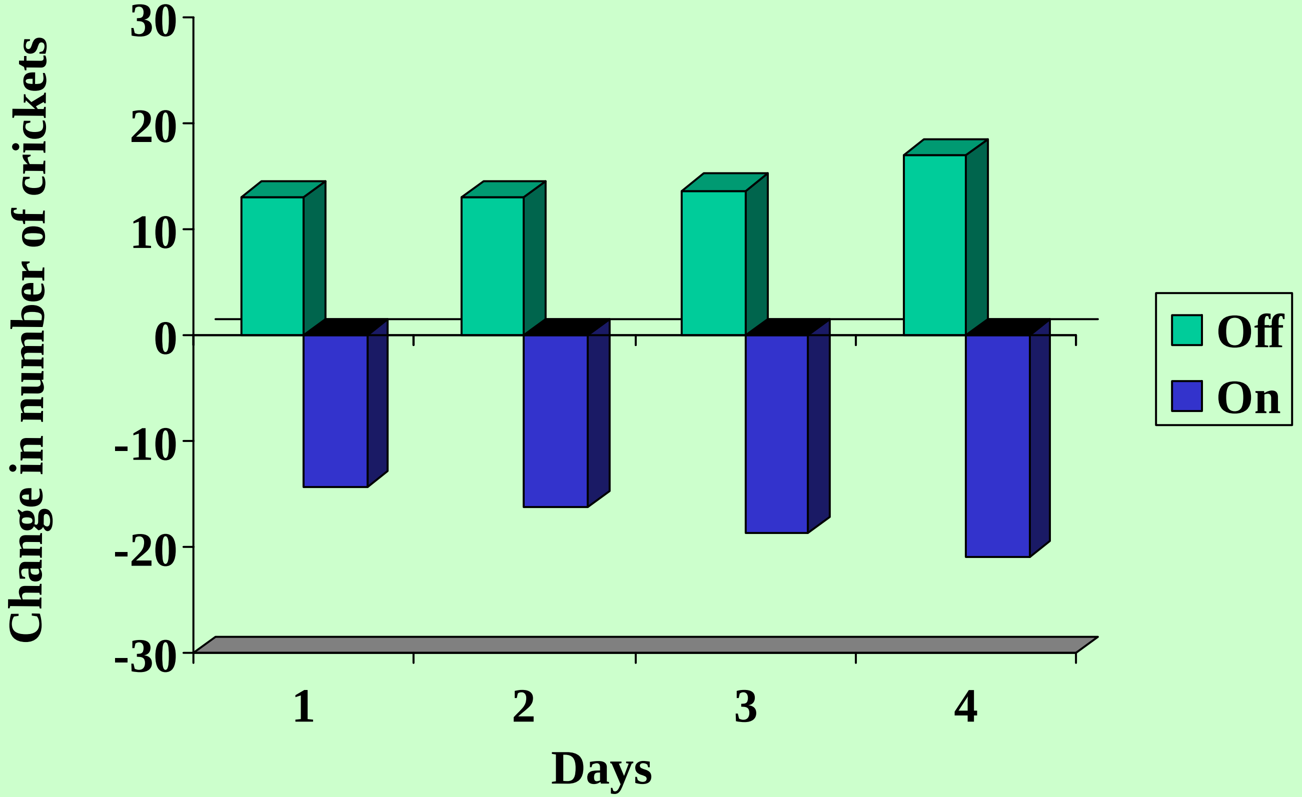
- House cricket purchased from Carolina supplies
- Devices A, C, D, E, and KSU unit
- 50 crickets/enclosure
- Replications: 3 for A and C, 1 for D and E, and 2 for KSU unit

- Number of crickets were counted daily
- 5-day test was a replicate
- Strip-split-plot design

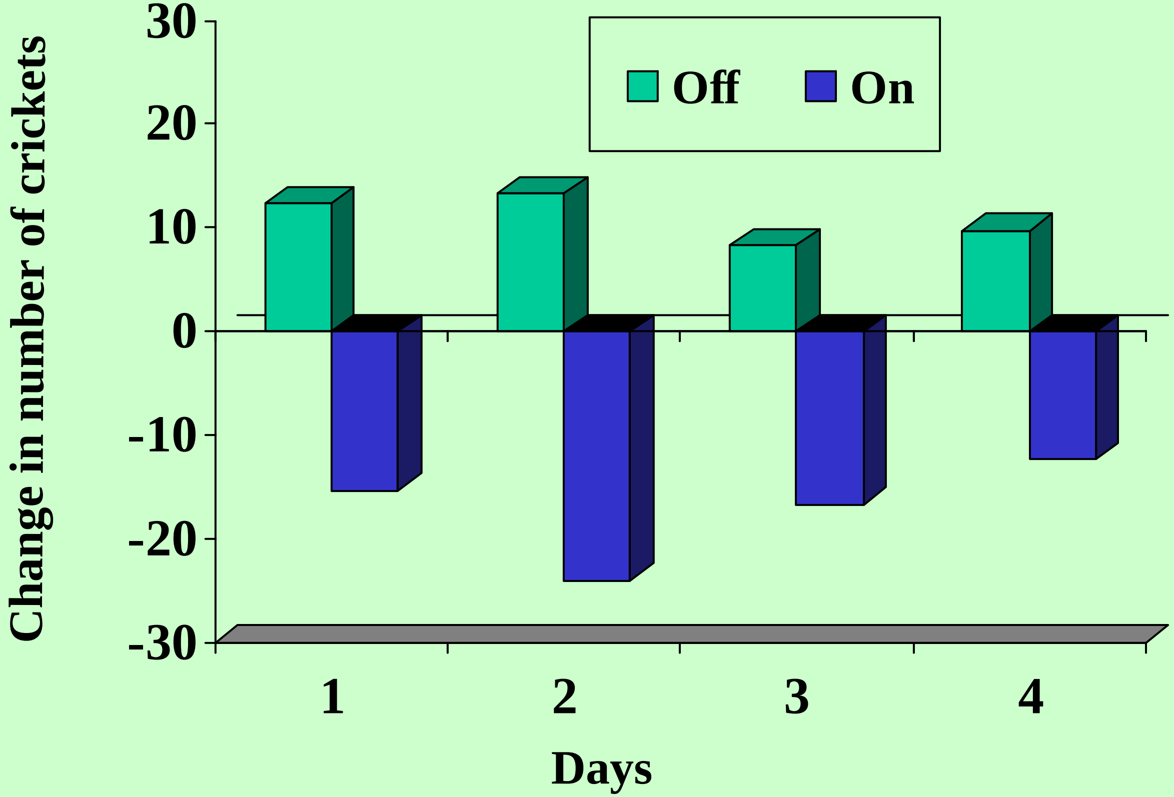


Day	Action		# of insects	
	A	B	A	B
0	Start	Start	100	100
1	off	off	xxx	xxx
2	on	off	xxx	xxx
3	on	off	xxx	xxx
4	off	on	xxx	xxx
5	off	on	xxx	xxx

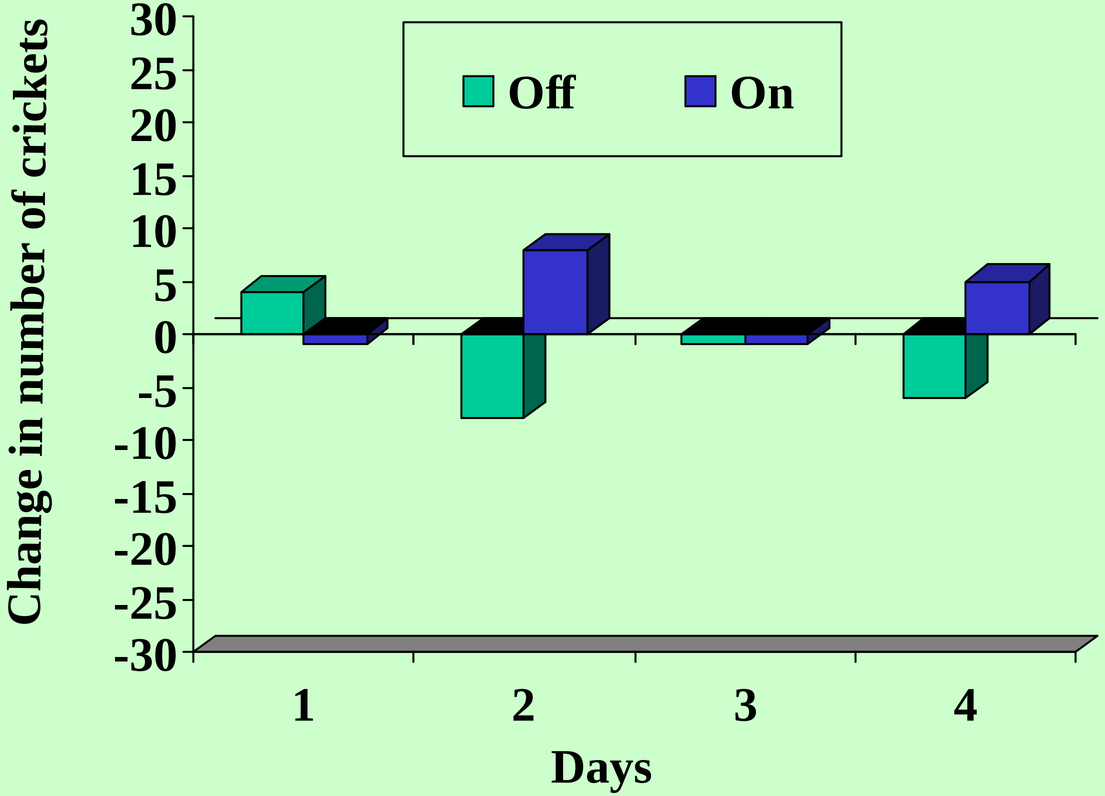
Device A test results



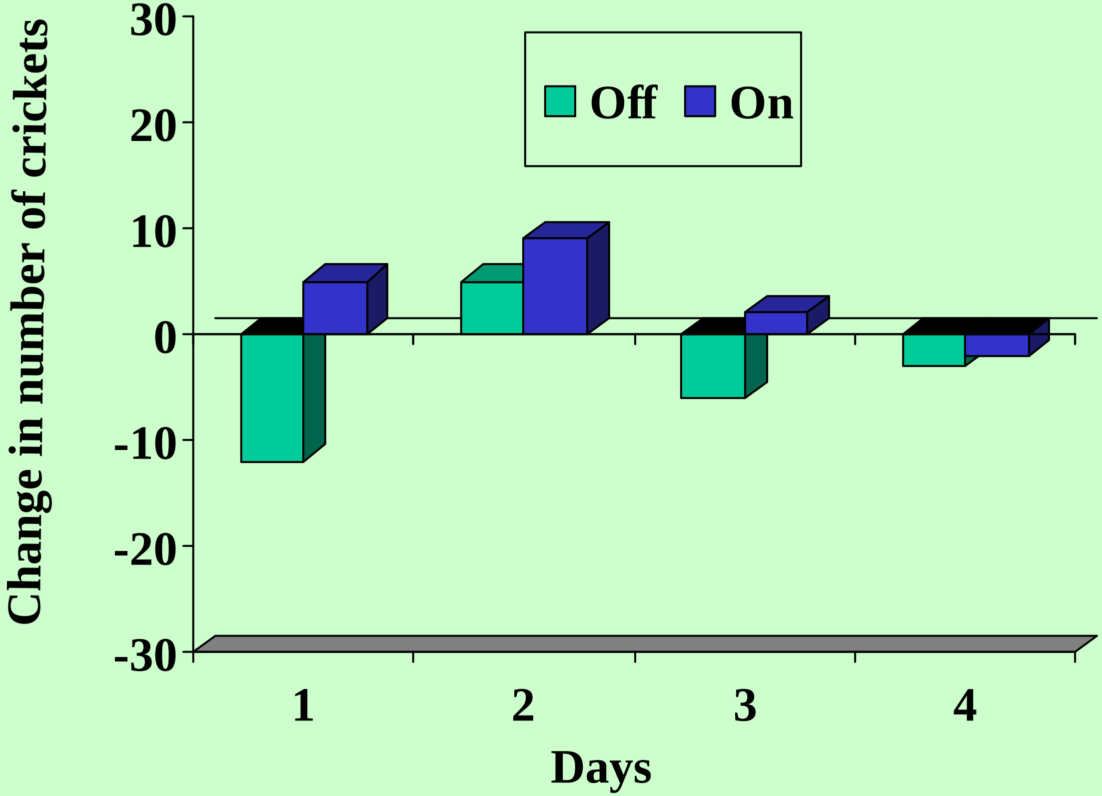
Device C test results



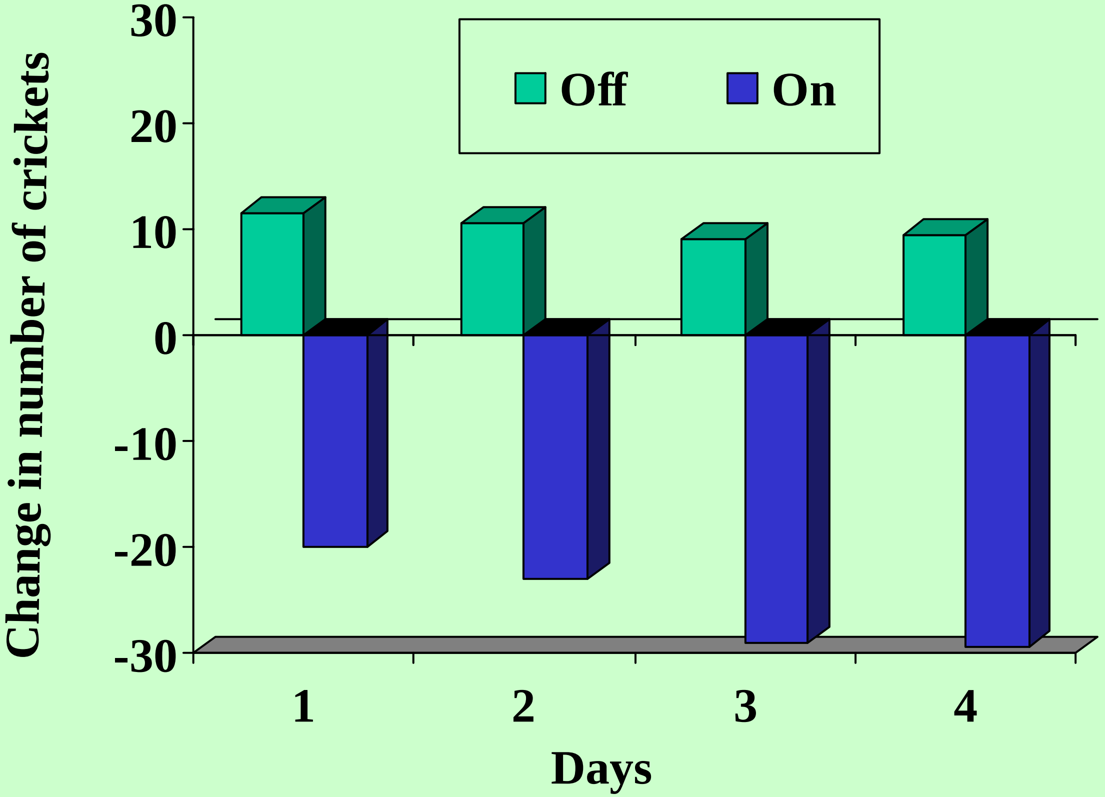
Device D test results



Device E test results



KSU device test results



Conclusions

- Devices A and C significantly repelled crickets. KSU unit repelled more crickets than A and C devices
- Device D and E performed poorly

Field Evaluation of three commercial ultrasonic devices in repelling flies and the eastern yellowjacket

Yellow jacket and Fly Tests

- Device A, B, and C.
- 18 metal buckets of 19.5-liter capacity were filled with fruits and pork meat mixed with trash
- One yellow jacket/fly sticky trap was taped upside down over the opening of each bucket
- Tuttle Creek Park at Manhattan, Kansas, with a 6.1 m distance between any two adjacent buckets
- Completely random design with 3 replicates
- After 10 days, insects in the sticky traps and buckets were recorded

Yellow jacket and Fly tests results

Device	Status	Fly complex # captured	Yellow jacket # captured
A	Inactive	13.3 ± 3.5 a	33.0 ± 5.9 a
	Active	16.7 ± 7.5 a	14.7 ± 6.3 b
B	Inactive	10.3 ± 5.8 a	19.3 ± 4.4 ab
	Active	22.0 ± 11.4 a	10.3 ± 3.9 b
C	Inactive	15.3 ± 4.6 a	22.7 ± 9.0 ab
	Active	20.3 ± 3.8 a	15.3 ± 2.2 ab

- Ultrasound produced from the three commercial devices failed to repel the fly complex
- Partially effective against the eastern yellowjacket

Ant tests

- Enclosure tests, similar to cockroach tests
- Open field test, similar as fly and yellow jacket tests

Enclosure test results

- No significant ant movement in the enclosures in the presence or absence of ultrasound

- Failed to repel ants

Open field test results

Treatment		Number of ants (Mean ± SE)		
Device	Status	In trap	Inside trashcan	Total[a]
A	Off	1.7 ± 1.7	8.0 ± 4.0	9.7 ± 5.7
	On	3.3 ± 2.4	6.0 ± 5.5	9.3 ± 7.8
B	Off	7.0 ± 7.0	7.0 ± 2.6	14.0 ± 7.0
	On	2.0 ± 2.0	7.3 ± 2.6	9.3 ± 1.5
C	Off	2.7 ± 2.7	10.0 ± 6.2	12.7 ± 8.8
	On	14.3 ± 12.4	11.3 ± 7.0	25.7 ± 12.8

- Failed to repel ants in field trials

Scorpion tests

Scorpion test procedure

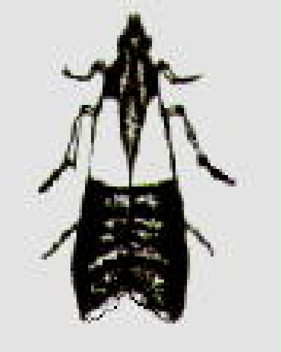
- Enclosure tests
- Imperil scorpion, *Pandinus imperator*
- Devices A and C
- For each ultrasonic device, 6 separate tests were conducted
- In each test, a scorpion (adult) was released into one of the paired enclosures and allowed to acclimate to the environment for 24 hours (day 0)
- After 24 h, the ultrasonic unit in one of the enclosures, in which the scorpion was located at that time was turned on for 7 days. The ultrasonic unit in the other enclosure remained off for the duration of the test
- The location of the scorpion was observed and recorded once a day

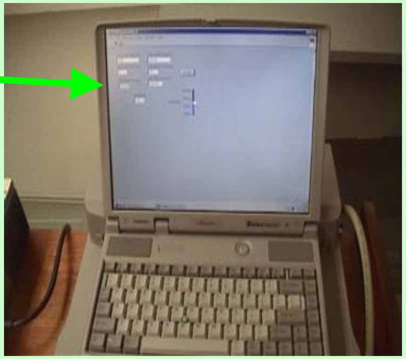
Scorpion test results

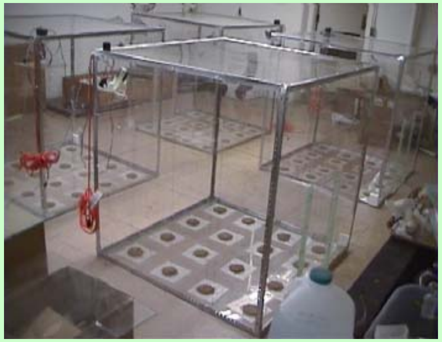
Device	Status	Times found in enclosure (%)
A	Inactive	68.4
	Active	32.6
B	Inactive	68.4
	Active	32.6

- The scorpions were more frequently found in the enclosure without ultrasound than in the enclosure with ultrasound
- 26 times the scorpions were located in the enclosure without ultrasound and only 12 times they were found in the enclosure with ultrasound across the six tests
- The limited data indicated that scorpions may respond to ultrasound produced by the two devices

Indian meal moth tests: effects on reproductive performance







- Device A and dKSU unit.
- Paired plexiglass enclosures
- 16 dishes or plastic sheets containing diet were placed in the base of the enclosures
- 10 pairs of newly emerged adults were released in each enclosure
- One ultrasonic device was turned on all the time and the another one was kept off at the same time or without an ultrasonic unit
- IMM distributions were recorded once or twice a day
- Number of larvae was checked after 18-30 days
- Dead females dissected to count spermatophores

KSU unit




- **2 transducers in one enclosure connected to a rotating arm**
- **Initial settings:**

-- Min Quiet Time (ms): 50.00

-- Max Quiet Time (ms): 500.00

-- Min Pulse Time (ms): 50.00

-- Max Pulse Time (ms): 200

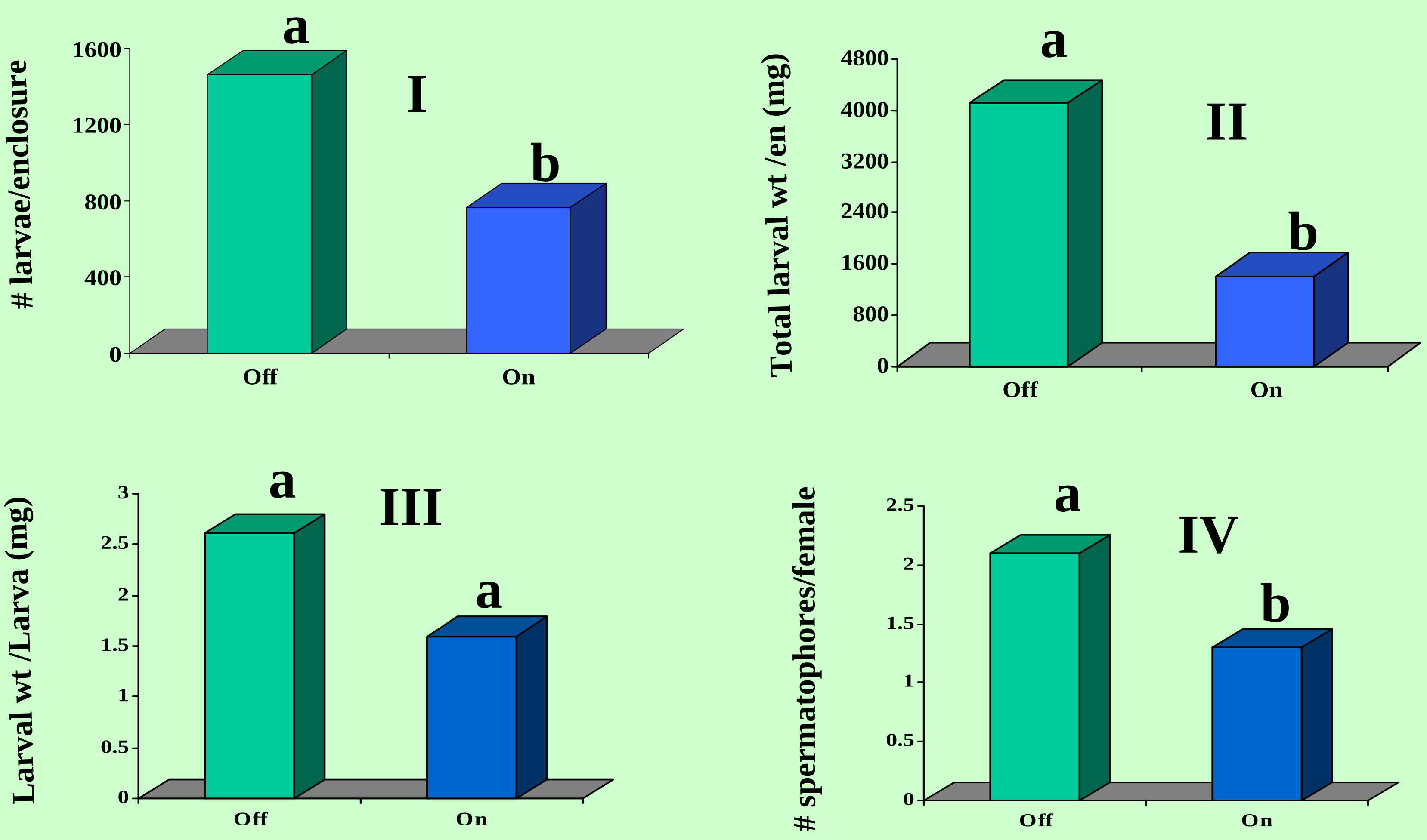
-- Min Step Size (Hz): 1000

-- Max Step Size (Hz): 5000

-- Amplitude: 2.25

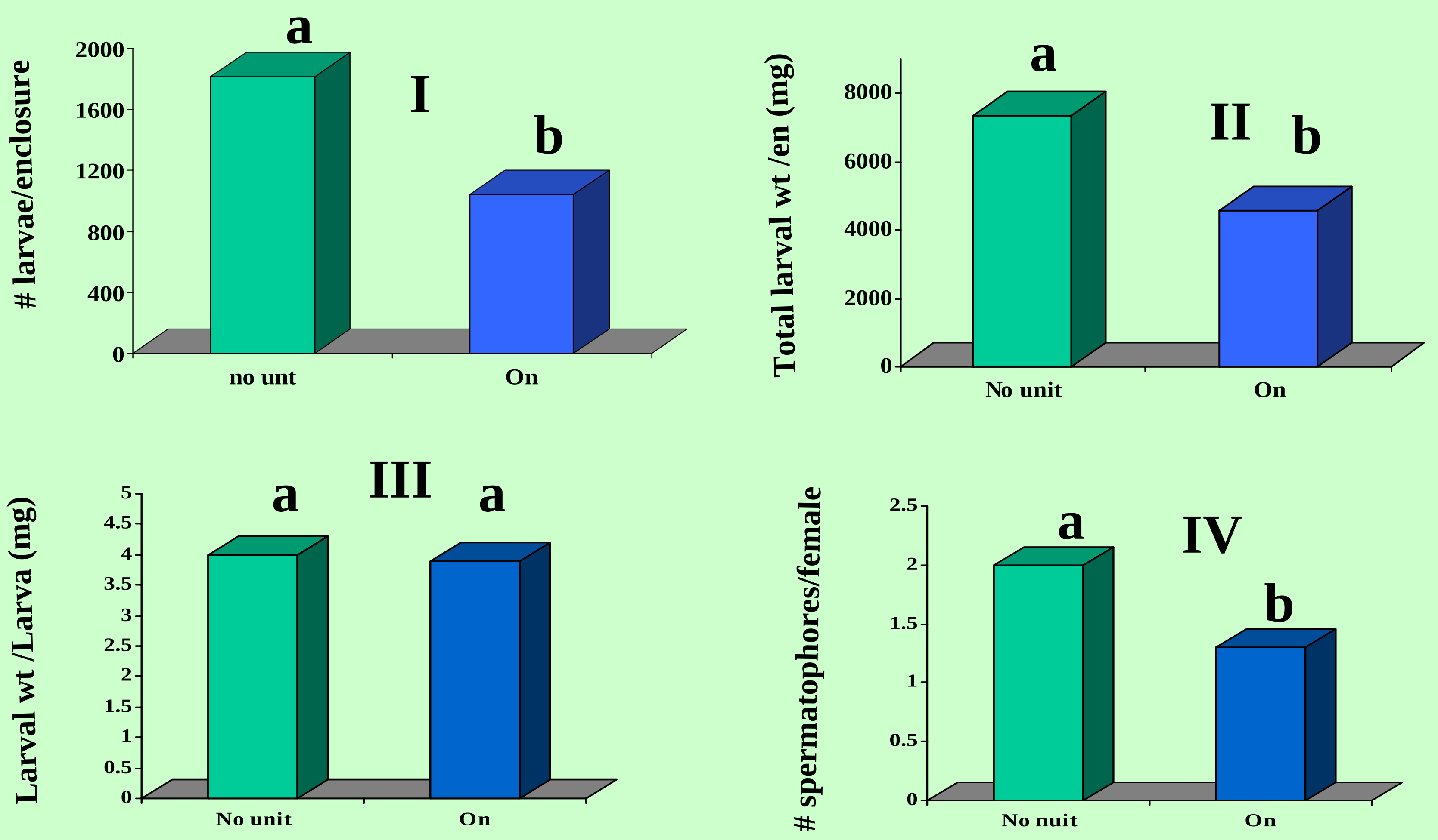
-- Frequency: 20,000-80,000 Hz

Indian meal moth test results, Device A



Number of larvae (I), larval weight (II & III), and spermatophores (IV) of Indianmeal moth under ultrasound exposure emitted from Device A

Indian meal moth test results, KSU device

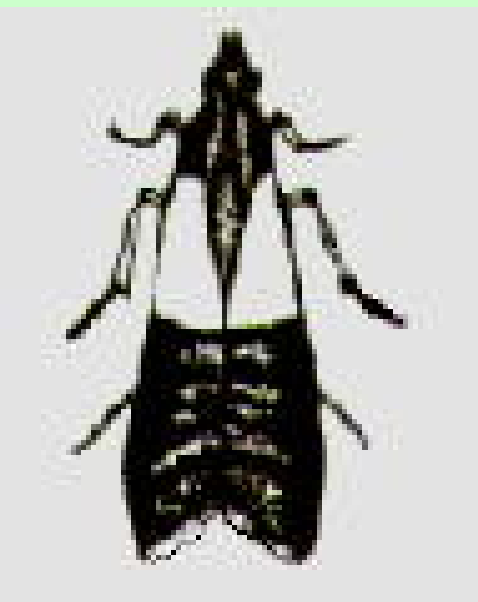


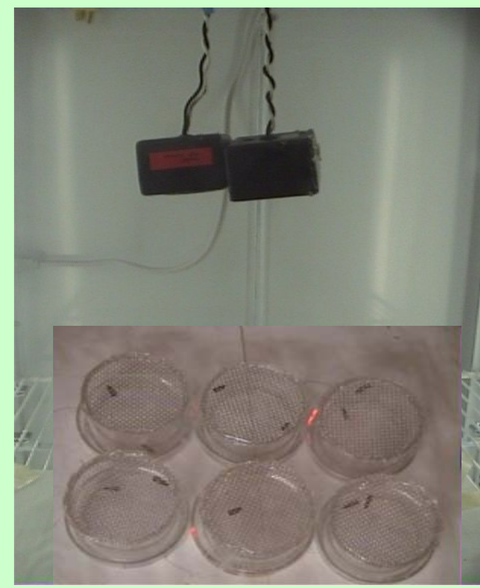
Number of larvae (I), larval weight (II & III), and spermatophores (IV) of Indianmeal moth under ultrasound exposure emitted from KSU unit

Conclusions

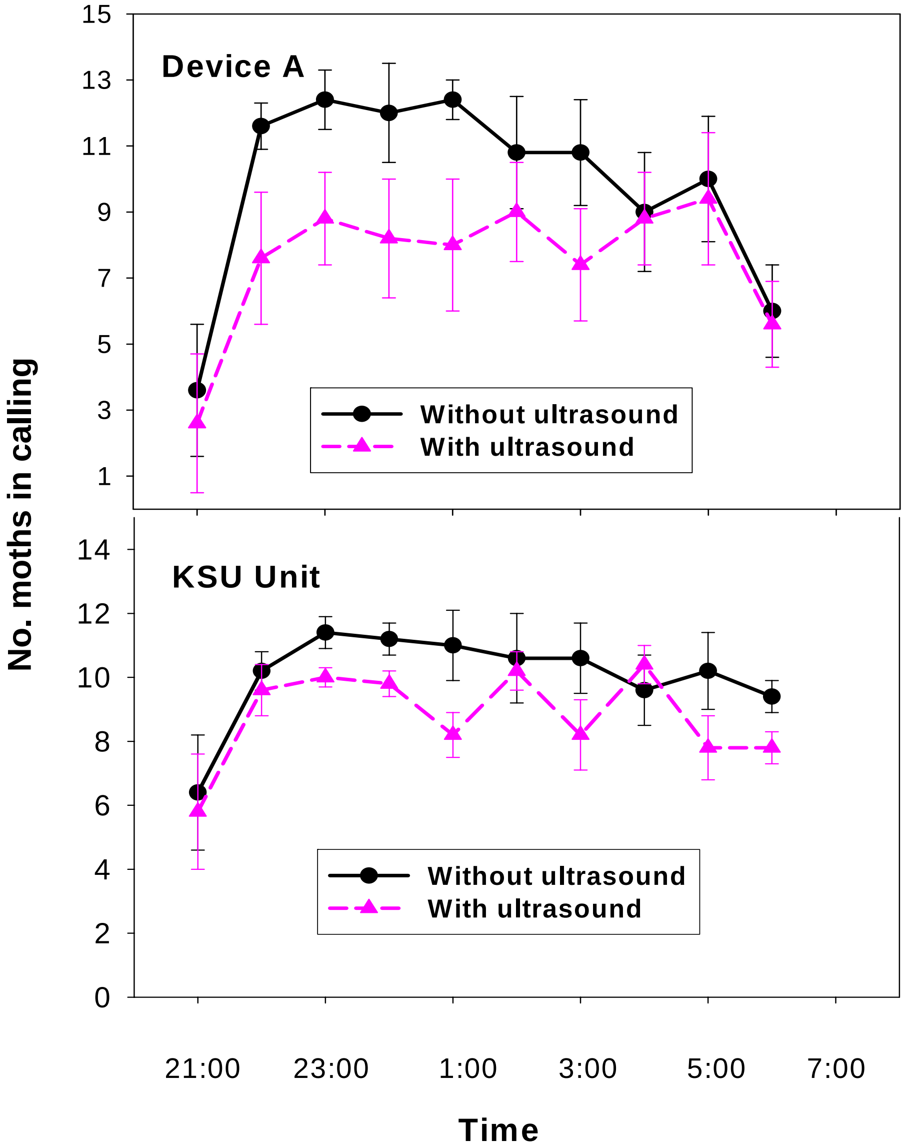
- 46% less number of larvae, and 57 % less total larval weight were observed
- A female had an average of 1.4 spermatophores under ultrasonic exposure compared to 2 spermatophores in the absence of ultrasound (control)

Effects of ultrasound on adult movement, courtship, and mating behaviors of Indian meal moth



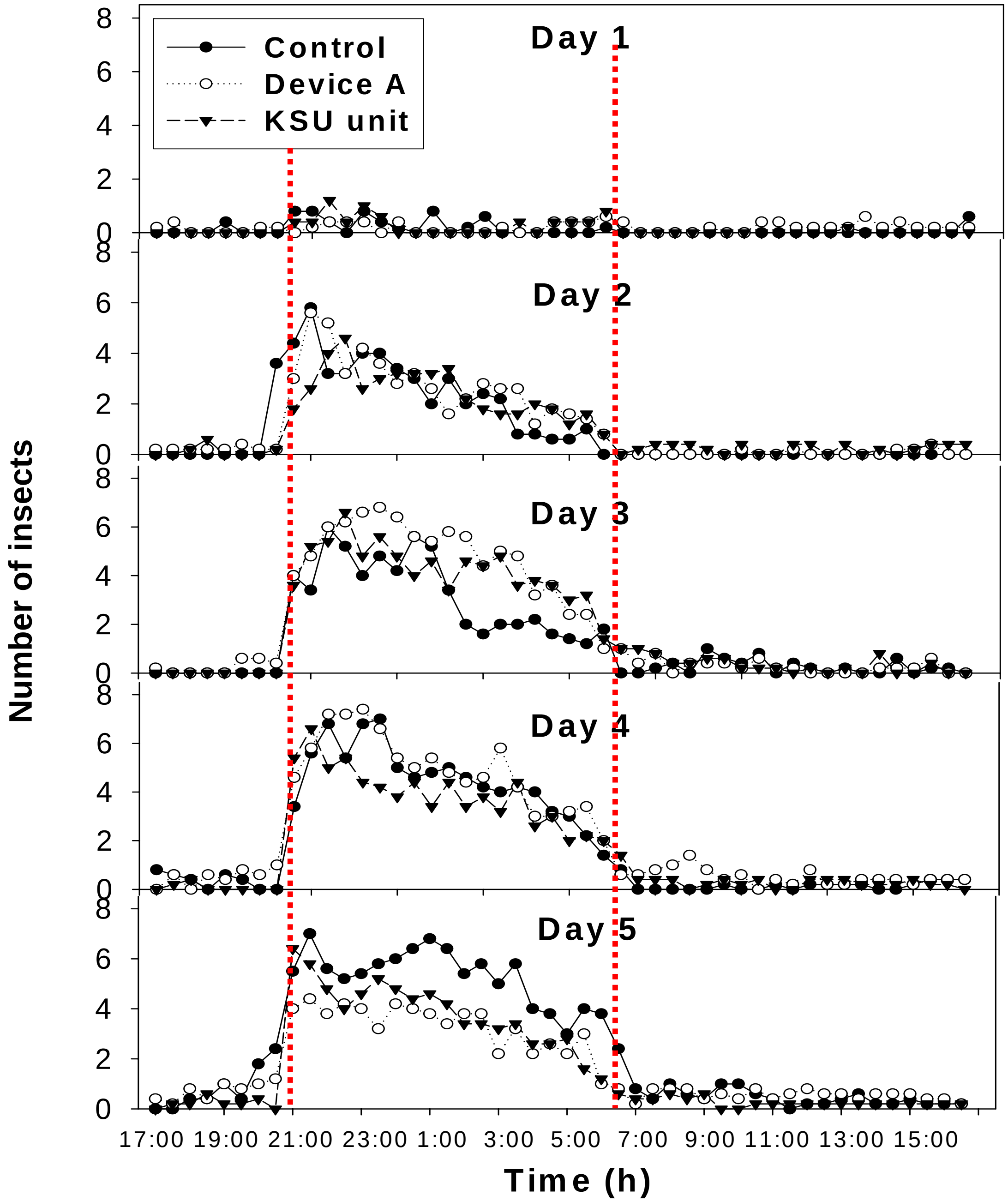


Results



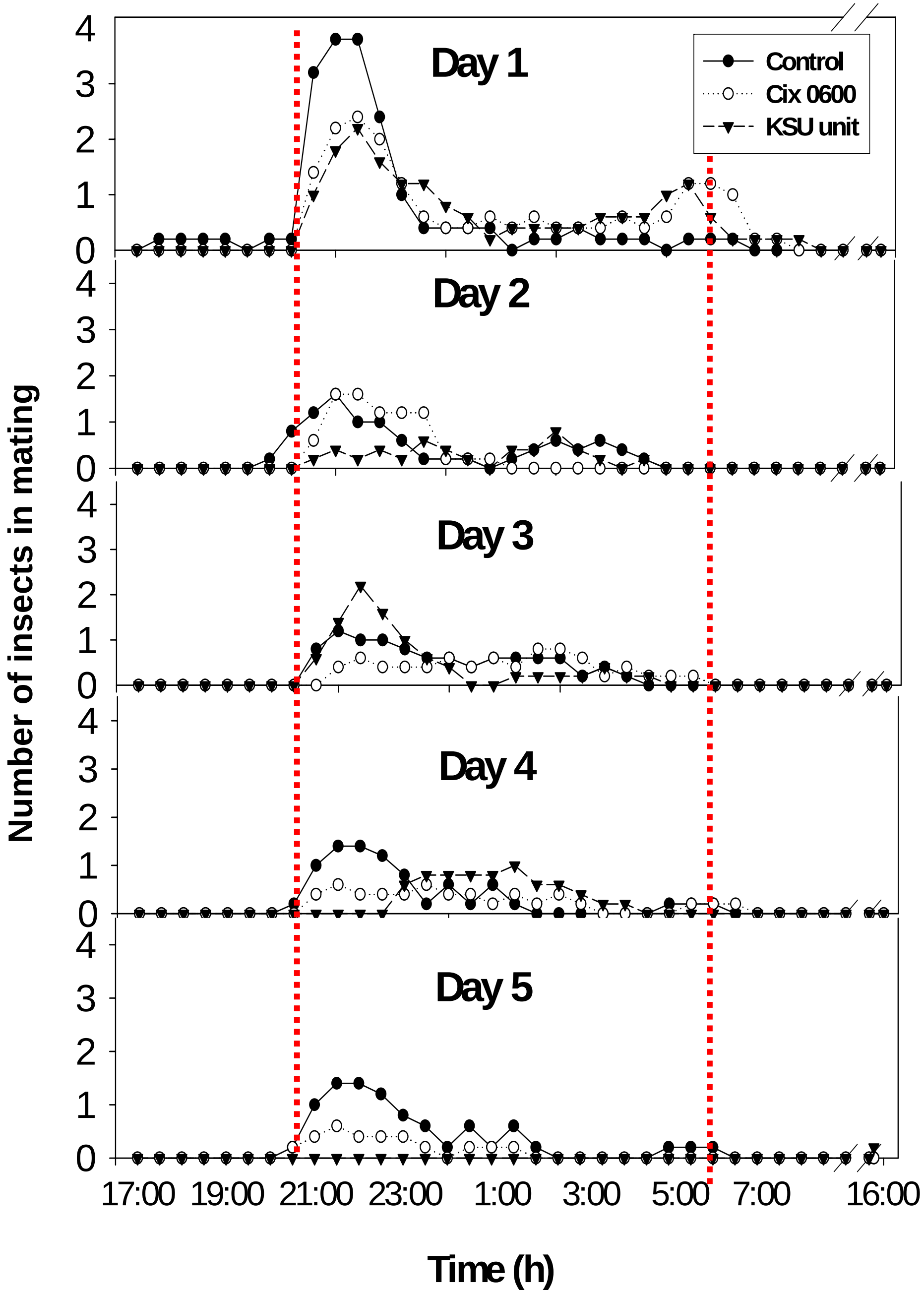
Female calling

- Calling occurred at night
- Less number of females were calling when exposed to ultrasound
- The difference was significant between 11:00 pm to 3:00 am



Adult movements

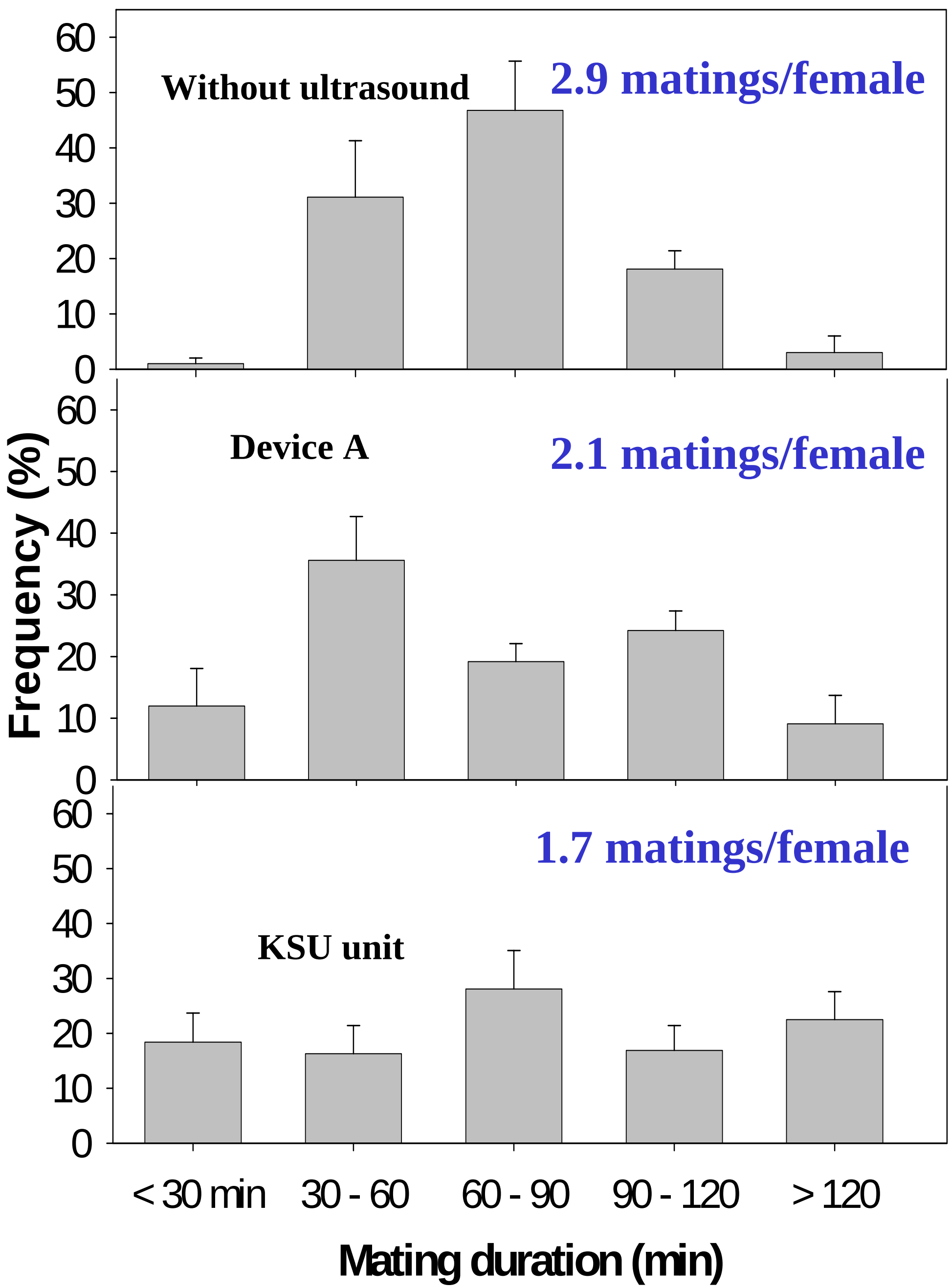
- Very little movement on day 1 and during day time
- Most movement occurred at night
- No obvious difference between control and ultrasound exposed moths



Mating activity

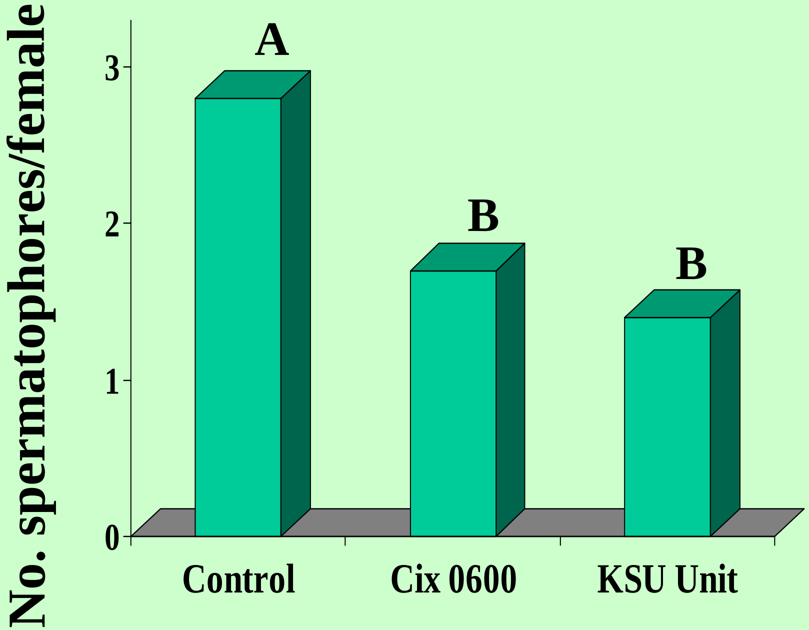
- No mating occurred during the day time
- Most matings occurred during the first night and between 9 pm and 11 pm
- No clear difference between control and under ultrasound exposed moths

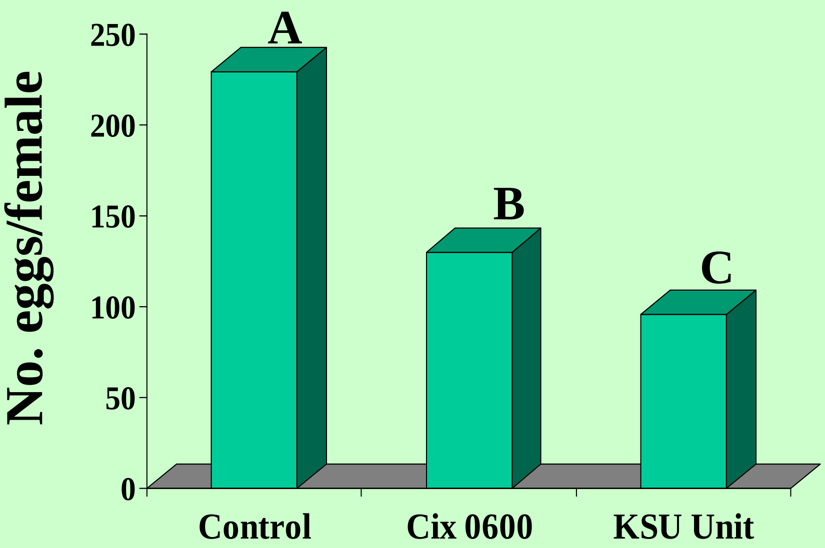
Mating duration

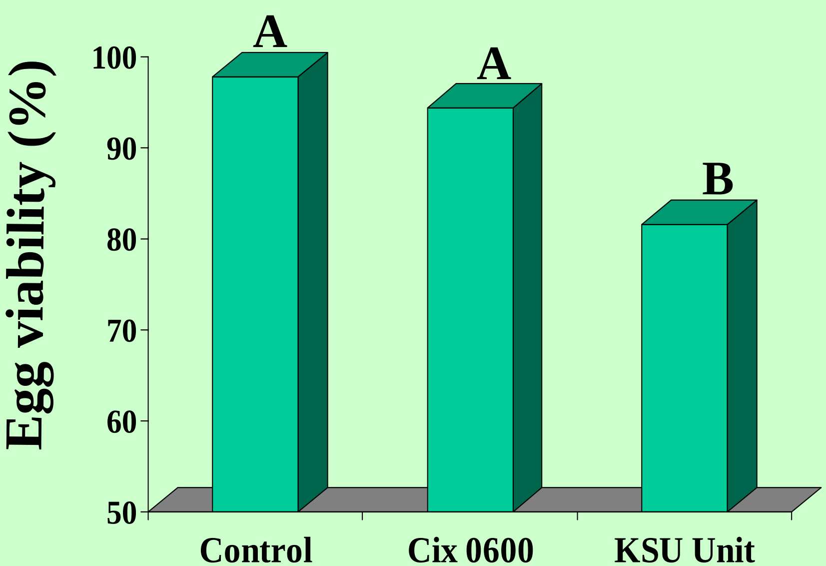


- A pair mated 3 times during their life time
- Significantly less number of matings occurred under ultrasound exposures
- Most matings lasted for 30 to 90 min without ultrasound
- More matings lasted for less than 30 min or more than 90 min under ultrasound exposure

Spermatophore transfer and reproduction







- **Ultrasound had significant impact on spermatophore transfer, number of eggs laid, and egg viability**

Ultrasound as a pest exclusion method

Repellency test results

Device	Status	Without diet		With diet	
		Enclosure A	Enclosure B	Enclosure A	Enclosure B
Control		53.6 ± 6.5 a	53.4 ± 6.8 a	88.6 ± 5.5 a	93.6 ± 4.6 a
Device A	A active	68.6 ± 3.2 a	71.8 ± 3.1 a	78.8 ± 11.4 a	107.0 ± 18.1 a
	B active	72.0 ± 10.7 a	68.6 ± 3.5 a	124.0 ± 14.4 a	87.0 ± 18.0 a
KSU device	A active	70.6 ± 7.8 a	61.6 ± 7.0 a	67.0 ± 7.9 b	98.0 ± 8.0 a
	B active	113.8 ± 7.9 a	81.6 ± 4.1 b	109.6 ± 14.9 a	85.0 ± 101.5 a

- The number of moths found in the enclosures with ultrasonic units were consistently fewer than those found in enclosures without ultrasonic units
- For device A, this difference was not significant (*P* > 0.05).
- For the KSU device, the differences were significant at the 10% level; and 2 out the 4 treatment combinations were significant at the 5% level

Summary of KSU tests

Devices	A	B	C	D	E	KSU
• Cat flea:	No effect	Good	Unclear			
• Cockroach:	Good	No effect	No effect	No effect	No effect	
• Ant:	No effect	No effect	No effect			
• Spider:	No effect	Unclear	Unclear	No effect	No effect	
• Y. jacket:	Fair	Fair	Fair			
• Cricket:	Unclear	No effect	Unclear	No effect	No effect	Fair
• Fly:	No effect	No effect	No effect			
• Scorpion	Unclear		Unclear			
• IMM	Good					Good

Key: Good | Fair | Unclear | No effect

Overall Conclusions

- The effectiveness of devices against arthropod pests cannot be ascertained without testing specific ultrasonic units
- Effectiveness varies with the protocol used
- Most tests are not done under “real world” conditions (background noises!)
- Repellency may not be the only criteria to evaluate effectiveness of ultrasonic units
- Best results were obtained with a tympanate moth

Future research needs

- Need to develop protocols for evaluating devices that reflect the “real world”
- Are devices being used for preventing or repelling infestations?
- Combination treatments should be explored
  - Light + ultrasound; ultrasonic barriers; ultrasound and attractants (push-pull strategy)
- Can environmental conditions within homes be altered for better performance of these devices?
- Need electrophysiological assays to ascertain effects (also for quick screening)
- Need to explore frequency ranges and pulse durations that give the best response (e.g., ranges above 45 kHz)
- May not have a promising future if existing devices are not improved through scientific and market research

Thanks