MECHANISM OF SOUND PRODUCTION AND RELATED RESPONSES IN SOME SPECIES OF GRYLLIDS

ABSTRACT

THESIS SUBMITTED FOR THE DEGREE OF
Doctor of Philosophy
IN
ZOOLOGY

BY
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Observations and experiments on the following six species, belonging to four genera of gryllids, were conducted in the laboratory as well as under field conditions. Detailed taxonomy of the species is provided in the text:

1. *Gryllus mitratus* Burmeister
2. *Gryllus bimaculatus* De Geer
3. *Gryllus domesticus* Linne
4. *Gryllodes sigillatus* (Walker)
5. *Pteronemobius fascipes* (Walker)
6. *Anaxipha longipennis* Serville

Crickets have been a subject of extensive studies for acoustic communication for the past forty years. With the advances in electronics and sound recording and analysis this study has received considerable significance. In more recent years such specialized fields as neurophysiology of sound production, phonotaxis etc., have been thoroughly investigated and large volume of literature has accumulated on the subject. While several countries of the world have contributed greatly to the subject, Indian cricket species have not received the amount of attention that they legitimately deserve. Only fragmentary account is available.
In India there is a well defined rainy season after summer and cricket species are most abundant during this season providing ample opportunities for the study of their life styles. It was decided to undertake research on various aspects of sound production such as mechanism of sound production, physical parameters of the acoustic signals and related responses with whatever facilities are available in Aligarh Muslim University. The results obtained have been suitably illustrated by sonograms, oscillograms, graphs etc.

Under the heading mechanism and the physical nature of songs the architectural patterns of the stridulatory files have been studied. Necessary data regarding the length of the files, regional tooth density and total number of teeth have been tabulated under each species. Different types of songs such as calling, precourtship, courtship and aggressive songs of all the species were recorded both under field and laboratory conditions. In *Gryllus domesticus* the first song produced by maturing male was also recorded and analysed. It was found that this amateur song contains long chirps which after 2-3 days transform into a normal calling song. Different parameters of songs such as pulse rate, chirp rate, pulse duration, inter pulse silent gap, carrier frequency and effect of temperature were studied from the sonograms.
The number \( n \) of teeth of the stridulatory file used in different pulses of each song was calculated by multiplying the pulse duration (sec) and frequency in cycles/second of all the species and the value of \( n \) was later confirmed by respective oscillograms. In some sonograms it was found that there is a sound signal in the interpulse silent gap which was initially supposed to be some type of acoustic aberration but when the same part was analysed in Oscillograms it was found that in the so called silent gap there were continuous sound signals though their amplitude was considerably low. From this analysis it was inferred that both the closing and opening movements of the tegmina are acoustically effective under certain environmental conditions. Experiments conducted on the mechanism of sound production can be summarized as follows:

1. The tooth impact rate determines the carrier frequency of the song.

2. The song frequency is the frequency of the tegmina as a whole or a part thereof.

3. Different songs have different frequencies.

4. At higher temperature range above 25°C opening motion of the tegmina is also acoustically effective and that

5. The frequency is generated by the tooth impact
Song related responses of individual species were studied in the field as well as under laboratory conditions. Due attention was paid to the daily rhythms, singing sites, alternation, baffle system and responses to light and temperature. Aggressive behaviour and dominance of males were studied under crowded conditions in the laboratory. It was found that when mature males of a species were enclosed in a jar or small cage the initial response between two adult males terminated in the withdrawal of one and the dominance of other. The retreat of one may be without any sign of aggressiveness or there may be a mild or intense aggressive postures exhibited by both the contenders followed by the retreat of the weaker one. Under such a condition when there is an initial reciprocal advance by the matching males it was found that a combat invariably follows during which parts of the bodies of both may be partially mutilated. Finally the defeated male withdraws. Straight combat was also invariably witnessed when an intruding male disturbed another guarding male. Another feature of crowding which was much in evidence was the cannibalistic tendency of the crickets. When suitable paper covers were provided within the cages cannibalism was considerably reduced and dominance of one male was established. Under
such a condition normal courtship song starts during which one of the males may mount.

In *Gryllus mitratus* and *G. domesticus* alternation of song rhythms was also observed under field conditions. During such an alternation the chirp rate of the alternating male is reduced to one half of that of the slow calling nonalternating male. In *Gryllodes sigillatus* and *Gryllus domesticus* with the night fall chorusing was also observed in residential quarters and in fields respectively.

During rainy season when the terrestrial hideouts of the crickets are flushed with water they usually begin calling from tree tops or nearby buildings. Such crickets usually utilize some kind of a 'baffle system' such as wall crevice, tubular tunnel, water hole and tree leaves to effectively transmit their sound over longer distances. Experiments conducted reveal that in order to maximise the efficiency of sound produced the crickets change their calling postures in relation to their immediate environment.

The sequential order of the mating behaviour of the opposite sexes has been studied in details in all the six species. *Anaxipha longipennis* was found to be specially interesting because in this species it is the male which
initiates the copulation by darting back under the stationary female and after sticking its spermatophore disengages the female within seconds. In the rest of the species it is the female which is lured for copulation by the courting male.

Necessary information regarding different parameters has been provided under each species in the text.
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BY
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June, 1986
This is to certify that Mr. Abdul Rauf
has completed his research under my supervision
for the degree of Doctor of Philosophy of the
Aligarh Muslim University, Aligarh. His thesis
entitled "Mechanism of sound production and
related responses in some species of gryllids"
is an original contribution and a distinct addition to the existing knowledge on the subject.
He is allowed to submit this work for the Ph.D.
degree of the Aligarh Muslim University, Aligarh.

( Dr. S.A. AZIZ )
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( A. RAUF )
I. INTRODUCTION

Years ago one fine evening after a heavy shower a large black cricket hovered about in my study and settled down on a bookshelf nearby. Soon after it started emitting loud sound comprising short musical notes of some attraction. This being the author's first encounter with a cricket of that size, it was decided that more should be known about its habits.

During monsoon season while strolling around the University Campus certain areas with abundant vegetation were found to be so noisy due to orchestration of sound producing creatures that temptation to carry out a search gradually mounted. A handy light source and a tape recorder were arranged. During preliminary survey, spread over several evenings, it was found that crickets of different sorts were abundant in that population. Some of them were brought to the laboratory for closer examination.

Insects were the first among the terrestrial animals that began to use acoustic signals for communication. The oldest record insects equipped with sound production mechanism has been found in fossils belonging to the Jurassic period i.e., 150-200 Ma (Alexander, 1966). Since that time their acoustic system has developed under the stress of increasing complexity of the acoustic environment. Factors such as speciation, differentiation of
intraspecific communication and emergence of other sound producing animals including insects and insect predators have affected the development of insect acoustic system. Among insects Orthopterans and Cicadas are the best known sound producing creatures. Crickets belong to the super family Grylloidea (Orthoptera) which are predominantly tropical omnivorous insects.

Since the second world war crickets have been a subject of intensive study for acoustic communication. It received further impetus with the advances in electronics and the techniques of sound recording and analysis. In more recent years the study has proliferated into such fields as neurophysiology of sound production, biophysics of sound production, circadian rhythms, mating behaviour, phônotaxis etc., and a voluminous literature has accumulated since then.

The author feels that research on insect acoustics along the above lines will be greatly facilitated if basic information about the behaviour of the individual species, the mechanism of sound production, physical parameters of acoustic signals, ecological factors to which they are adapted and the related responses to the sonic signals is available. While several countries of the world have contributed greatly towards this knowledge,
practically no work, so far as the knowledge of the present author goes, has been done on Indian gryllids. Whatever information is available is scanty and inconclusive.

The present research was therefore, undertaken with a view to study the structure of sound producing apparatus, its functioning and the process of translating the biophysical properties of sound producing apparatus into the physical parameters of songs. Responses relating to interaction between similar and opposite sexes have been studied under field and laboratory conditions. Special attention was paid to daily rhythms, singing sites, alternation and synchronism, baffle system and response to light and temperature. For the present study the following six species of gryllids were selected:

1. *Gryllus mitratus* Burmeister
2. *G. bimaculatus* De Geer
3. *G. domesticus* Linne
4. *Gryllodes sigillatus* (Walker)
5. *Pteronomobius fascipes* (Walker) and
6. *Anaxipha longipennis* (Serville)

In the text the bulk of information on different parameters has been provided under each species in order to avoid unnecessary repetition. Comparision
with other species has been attempted wherever found necessary. The description has been suitably illustrated by sonograms, oscilograms, graphs and photographs. This work, it is hoped will provide some basic information for advanced research on the subject. Its taxonomic importance apart, the information contained herein may be profitably utilised in the development of sonic traps, attractants and repellents in regions where these species are regarded as pests.
II. MATERIALS AND METHODS

The gryllid species were reared in the laboratory and at the Zoological Field Station (Fort area) in cages measuring 30 cm x 30 cm x 30 cm and glass jars of 20 cm x 15 cm and 15 cm x 10 cm. The floor of the cage and two sides were paneled with wood in one of which was a small window, the rest was covered by glass and the roof by thin wire gauze. Natural and artificial diet as recommended by Busvine (1955) was regularly provided in cages. For *P. fascipes* and *A. longipennis* natural habitat was created by planting *Cynodon dactylon* in the jars. The crickets are highly cannibalistic. In order to minimise inflighting pieces of papers were folded and placed in jars and cages to provide covers for the inmates. During inclement weather the jars and cages were kept in cabinets maintained at 27 + 2°C and 70 + 5% R.H.

The stridulatory files of both the tegmina were studied in living as well as preserved specimens. Permanent whole mounts of the tegmina were prepared for the study of architecture and tooth density. A compound microscope with an attached micrometer was used for microphotographs of all the files.

The gryllids invariably keep their right tegmen over the left but sometimes a reversal of position also occurs in nature. For experimental purpose the position
of forewing was reversed in anaesthetized specimens and the results were noted. Cricket songs were recorded in the Ecology laboratory and field station. Some sound recordings were also done in sound proof speech Research laboratory in the department of Physics, Aligarh Muslim University, Aligarh. Different types of songs were recorded with portable tape recorder (Raider Model 9100R) and professional recorder (Grundig TK 27) having facilities for monitoring, recording level and tape footage indicator. Directional microphone (Sony Cordoid No. F-25 IMP Low) was used as recommended by Haskell (1964). The microphone was always placed 5-10 cm above the singing males. The calling males were put inside recording cage or jar and placed in dark room several hours before the recordings were made. The intensity of the songs was measured by sound level meter (Bruel and Kjaer 2225) with 0.5 dB resolution. Different songs of all 6 species were analysed with the help of Sona-Graph 7029A (5-16000 Hz spectrum analyser) in the sound proof speech research laboratory in the department of Physics in this University. Song Carrier frequency of each has been noted, the chirp and trill duration and silent intervals between them have been measured in the sonograms. Individual pulses of different songs are of short duration and attempts have been made
to measure them as accurately as possible through travelling microscope. The number of sound waves emitted in a single pulse were computed by the simple formula $n = F \times t$ (where $n$ represents the number of waves in a pulse, $F$ the frequency of the pulse in cycles per sec. and $t$, pulse duration in seconds). These results were confirmed later by photographing Oscillograms of different pulses of the song stored in the Digital memory by feeding the electrical signal from the tape recorder into TS-8123 Storagescope (IWATSU ELECTRIC CO. LTD. JAPAN). This analysis was done in the Electronics research laboratory, department of Electrical Engineering Z.H. College of Engineering and technology. The sonograms provide only an approximate value of the carrier frequency of a single pulse. In order to obtain frequencies, a graph of distance versus frequency was plotted from frequency calibration curve of 1 kHz in the range of 80 Hz - 8 kHz or 160 Hz - 16 kHz as the case may be. Time was measured by calibrating the sonograph with 50 Hz in wide band scale and it was found to be 16 m sec/mm and 8 m sec/mm.

The temperature plays an important role in the cricket sound production. The test crickets were placed individually in small cages (10 cm x 10 cm x 10 cm) or
in glass jars 15 x 10 cm. The calling male was exposed to the test temperature in BOD incubator (Orien, Orient Traders) for at least one hour before recording the song. The temperature was gradually raised from 10°C to 38°C with a 2-3 degree rise at every stage and after two hours test exposure observations were taken. In nature the crickets usually sing at night, those in captivity behave the same way. For sound recording the gryllids were kept in cages in the BOD cabinet, whose machine was switched off at the time of recording to avoid background noises. Calling songs of 5-10 individuals of each species were recorded at various temperatures ranging from 15°C - 38°C and 70 ± 5% R.H. The wing stroke rate was determined by taking 10-15 sonograms for each temperature since each sonogram covers only 1.2 - 2.4 seconds of singing. These results were plotted on graph papers and eye fitting line was drawn for each species.

Correlation coefficient elucidates the nature and degree of relationship between two characteristics. Due to this correlation, variation in one variable brings about corresponding change in the other. This enables us to predict the value of one variable from the knowledge of the other.

The regression line 'best' fitting the observations was calculated from the following formula.
\[
\hat{Y} = a + bX \\
b = \frac{\Sigma XY - (\Sigma X)(\Sigma Y)}{\Sigma X^2 - (\Sigma X)^2} \\
a = \bar{Y} - b\bar{X}
\]

Where \( \hat{Y} \) (\( Y \)-hat) indicates the predicted value of \( Y \) for a given value of \( X \).

\( X, Y \) are observations of two factors, viz., temp°C and pulse/sec.

\( a, b \) are constants

\( \bar{X}, \bar{Y} \) are the arithmatic means of all the observations of the respective variables (\( X \) and \( Y \))

The expected temperature (\( X \)) for 0 pulse rate (\( \hat{Y} = 0 \)) which equals \( -a/b \) was calculated for each species.

Data on cricket population in the field were collected from desired localities by closely observing them in their natural environment sometimes for hours together without disturbing them. One reason why statistics could not be applied to such field observations is that adequate number of replicates were not available in respect of certain parameters in a limited time and locality due to the mobility of these insects and their hideouts in the natural environment.

The study of responses in the laboratory was carried out on both field collected and laboratory reared virgins. Collections were made in the early evenings and
late nights from the Zoological Field Station (Text Fig. 1) and about $\frac{1}{2}$ km around. The crickets are ferocious cannibals and were, therefore, kept in separate jars. Only during experiments they were allowed to mix together.

For studying the interaction and responses among males, 5 calling males were kept in each of the 10 jars (20 x 15 cm) and their territorial and offensive behaviour was observed. Most of the observations were taken at night.

Male to female response in the laboratory was studied in simple glass chambers of 14 cm x 14 cm x 10 cm and 11 cm x 11 cm x 8.5 cm size. P. fascipes, and A. longipes species being small were placed in smaller chambers. The observations were made at night under red light conditions. For observations on mating behaviour one pair was released in a glass chamber at a time and the sequence of mating was closely observed and photographed. Twenty such pairs of each species were released in glass chamber maintained at 27°- 30°C. In a few studies a virgin calling male was put in the glass chamber where a pair had just mated and the male was guarding the female. Fighting and offensive songs were recorded and the aggressive postures photographed.

The block diagram and photographs of the recording and analysis system is given in Text Fig. 2 and Plate 1-3. All the cassettes and specimens studied have been deposited in the department of Zoology, A.M.U., Aligarh, India.
Text Fig. 1

Diagrammatic representation of the Zoological Field Station (Fort Area).
Text Fig. 2

Block diagram of recording and analysis system
III. METEOROLOGY OF THE AREA

The zoological field station and the surrounding area has a dry and tropical monsoon type of climate with seasonal rhythm marked by north-east to south-west monsoon. Climatically the year is divisible into three well defined seasons viz. winter, summer and monsoon.

Winter (Mid October to mid March):

The beginning of winter season is marked by a considerable fall in temperature (Table 1). In this season a relatively low pressure exists over the Indian seas, thus causing the winds to blow from plains towards the seas. The mean maximum temperature falls from 31.1°C in November to 24.2°C in December and to 22.5°C in January, the minimum falls while/from 13.2°C in November to 10.7°C in December and to 9.7°C in January (Table 1). In these months the nights are very cold and the days are comparatively warmer with usually foggy mornings.

Predominating direction of winds during the winter season is from West and North-west to south and south-east. The winds during this season are light and blow at an average speed of about 7 km per hour. The winds are dry and of continental origin. Occasional winter rain are brought about by the cold weather storms. The rainfall is irregular and sporadic (Table 2). By the end of February, the temperature begins to rise (Table 1).
Table 1

Mean monthly temperature at Zoological field Station at Aligarh (based on five years data).

<table>
<thead>
<tr>
<th>Months</th>
<th>°C minimum</th>
<th>°C maximum</th>
<th>°C Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>9.7</td>
<td>22.5</td>
<td>16.1</td>
</tr>
<tr>
<td>February</td>
<td>11.8</td>
<td>23.0</td>
<td>19.9</td>
</tr>
<tr>
<td>March</td>
<td>16.9</td>
<td>43.0</td>
<td>29.9</td>
</tr>
<tr>
<td>April</td>
<td>22.1</td>
<td>47.0</td>
<td>34.4</td>
</tr>
<tr>
<td>May</td>
<td>24.3</td>
<td>44.7</td>
<td>34.5</td>
</tr>
<tr>
<td>June</td>
<td>28.0</td>
<td>45.3</td>
<td>37.6</td>
</tr>
<tr>
<td>July</td>
<td>26.8</td>
<td>30.8</td>
<td>33.3</td>
</tr>
<tr>
<td>August</td>
<td>25.9</td>
<td>37.2</td>
<td>31.5</td>
</tr>
<tr>
<td>September</td>
<td>23.8</td>
<td>36.9</td>
<td>30.3</td>
</tr>
<tr>
<td>October</td>
<td>23.8</td>
<td>36.2</td>
<td>30.0</td>
</tr>
<tr>
<td>November</td>
<td>14.2</td>
<td>33.1</td>
<td>22.1</td>
</tr>
<tr>
<td>December</td>
<td>10.7</td>
<td>24.2</td>
<td>17.4</td>
</tr>
</tbody>
</table>

Source: Meteorology Section (Dept. of Physics)
Table: 2

Mean monthly rainfall (mm) at Zoological field station during the study period.

<table>
<thead>
<tr>
<th>Months</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>0.85</td>
<td>2.15</td>
<td>1.50</td>
</tr>
<tr>
<td>December</td>
<td>5.05</td>
<td>14.35</td>
<td>9.70</td>
</tr>
<tr>
<td>January</td>
<td>11.00</td>
<td>27.40</td>
<td>19.35</td>
</tr>
<tr>
<td>February</td>
<td>10.85</td>
<td>25.15</td>
<td>17.80</td>
</tr>
<tr>
<td>March</td>
<td>1.85</td>
<td>4.15</td>
<td>2.30</td>
</tr>
<tr>
<td>April</td>
<td>2.10</td>
<td>5.30</td>
<td>3.70</td>
</tr>
<tr>
<td>May</td>
<td>0.60</td>
<td>1.40</td>
<td>1.00</td>
</tr>
<tr>
<td>June</td>
<td>17.7</td>
<td>43.40</td>
<td>30.35</td>
</tr>
<tr>
<td>July</td>
<td>112.65</td>
<td>302.25</td>
<td>207.45</td>
</tr>
<tr>
<td>August</td>
<td>112.35</td>
<td>333.65</td>
<td>225.60</td>
</tr>
<tr>
<td>September</td>
<td>63.2</td>
<td>236.75</td>
<td>152.50</td>
</tr>
<tr>
<td>October</td>
<td>10.1</td>
<td>24.85</td>
<td>17.50</td>
</tr>
<tr>
<td><strong>ANNUAL</strong></td>
<td>357.50</td>
<td>1050.80</td>
<td>689.15</td>
</tr>
</tbody>
</table>

Source: Meteorology Section (Dept. of Physics)
Summer (Mid-March to mid-June):

This season begins with March and continues till June. Its beginning is marked by an appreciable rise in temperature and decrease in pressure. Due to wide range of temperature during summer months, the days are warm and nights are pleasant. The maximum and minimum temperature in March are 43.0°C and 16.9°C, respectively. The temperature continues to rise in April and the average maximum and minimum temperature, touch 47.0°C and 22.1°C, respectively. In the months of May and June, the mean maximum temperature continues to be as high as 44.7°C and 45.3°C (Table 1). The days are characterized by hot and dry air, the relative humidity being 31.45% in May (Table 3).

The hot winds blowing with high velocity during daytime happen to be a regular phenomenon. The velocity of winds begins to increase steadily from March when average wind speed is about 6.8 km per hour and reaches the maximum 8.87 km per hour in June. The monthly averages, however, do not give a correct idea of the velocity of these winds as it is liable to great variations during the twenty four hours. The wind speed rapidly increases from 8 am. to 1 pm. and blows almost with the force of gale during next 2-3 hours and then falls again very rapidly by 6 pm. At night it turns into a breeze.
Table: 3

Mean monthly Relative Humidity (%) at Zoological field station during the study years.

<table>
<thead>
<tr>
<th>Months</th>
<th>8.30 hrs.</th>
<th>17.30 hrs.</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>November</td>
<td>57.0</td>
<td>36.5</td>
<td>47.15</td>
</tr>
<tr>
<td>December</td>
<td>79.0</td>
<td>50.6</td>
<td>64.8</td>
</tr>
<tr>
<td>January</td>
<td>85.2</td>
<td>52.0</td>
<td>68.6</td>
</tr>
<tr>
<td>February</td>
<td>82.0</td>
<td>44.0</td>
<td>63.0</td>
</tr>
<tr>
<td>March</td>
<td>67.3</td>
<td>26.0</td>
<td>44.65</td>
</tr>
<tr>
<td>April</td>
<td>41.6</td>
<td>24.4</td>
<td>32.95</td>
</tr>
<tr>
<td>May</td>
<td>40.4</td>
<td>22.5</td>
<td>31.45</td>
</tr>
<tr>
<td>June</td>
<td>53.4</td>
<td>38.4</td>
<td>45.9</td>
</tr>
<tr>
<td>July</td>
<td>93.0</td>
<td>60.0</td>
<td>71.5</td>
</tr>
<tr>
<td>August</td>
<td>91.5</td>
<td>71.1</td>
<td>81.3</td>
</tr>
<tr>
<td>September</td>
<td>86.0</td>
<td>67.0</td>
<td>76.5</td>
</tr>
<tr>
<td>October</td>
<td>58.3</td>
<td>36.5</td>
<td>47.4</td>
</tr>
<tr>
<td><strong>ANNUAL</strong></td>
<td><strong>68.417</strong></td>
<td><strong>44.083</strong></td>
<td><strong>56.25</strong></td>
</tr>
</tbody>
</table>

Source: Meteorology Section (Dept. of Physics).
There are frequent dust and thunder storms in the afternoon of summer days, sometimes accompanied by rain. The wind velocity reaches 50-60 km per hour. The frequency and velocity of such storms increase with the advancing season. The rains are rare, sporadic, short lived and highly variable. The total rainfall during summer (March to June) is 37.85 mm (Table 2).

Monsoon (Mid-June to mid-October):

The atmospheric temperature falls with the arrival of south and south-west monsoon and the air becomes cool and pleasant by the late June. The average maximum and minimum temperature falls from 45.3°C and 28.0°C to 39.8°C and 26.8°C in July (Table 1). The relative humidity increases from 45% in June to 71% in July (Table 3). The sky is generally overcast in the season.

The time of onset and retreat of the monsoon varies from year to year. The rains generally set in by late June or early July and continue till the end of September or October. The maximum rainfall recorded in August is about 333.65 mm (Table 2).
IV. SYSTEMATICS OF THE SIX GRYLLID SPECIES STUDIED

In the present study six species, *Gryllus mitratus* Burmeister; *G. bimaculatus* De Geer; *G. domesticus* Linne; *Gryllodes sigillatus* (Walker); *Pteronemobius fascipes* (Walker) and *Anaxipha longipennis* (Serville) are included (Plate II and III). The distinguishing characters of these species have been given in detail by Chopard (1969).

FAMILY GRYLLIDAE

A. SUBFAMILY GRYLLINAE

**Gryllus mitratus** Burmeister

(Pl.II-4)


**Gryllus bimaculatus** De Geer

(Pl.II-5)

*Gryllus bimaculatus* De Geer, 1773, *Mem. Ins.*, 3:521, pl. 43, Fig. 4.


**Gryllus domesticus** Linne

(Pl.II-6)


Gryllus *domesticus* Saussure, 1877, Mem. Soci. Geneve, 25; 173


**Gryllodes sigillatus** (Walker)

(Pl.III-7)


Homaloblellum *indicus* Bolivar, 1900, Ann. Soc. ent. Fr. 68; 800 (Syn.quoted by Chopard, 1969, Faun. India, Orth. Grylloidea 2: 85).

Gryllus *palliclус* Chopard, 1928, Rec. Ind. Mus., 30; 11, Fig. 19 (Syn.quoted by Chopard, 1969, Faun. India, Orth. Grylloidea, 2: 85).

B. SUBFAMILY NEMOBIINAE

Pteronemobius fascipes (Walker)

(Pl. III-8)

Nemobius histrio Saussure, 1877, Mem. soc. Geneve, 25:95
Pteronemobius histrio Chopard, 1924, Rec. Ind. Mus., 26:182
Pteronemobius fascipes Chopard, 1931, Bull. Raffles Mus. No. 6:134
Pteronemobius fascipes (Walker); Chopard, 1969, Faun. India Orth. Grylloidea 2: 164

FAMILY TRIGONIDIIDAE

Anaxipha longipennis (Serville)

(Pl. III - 9)

Trigonidium longipenne Serville, 1839, Ins. Orth, 351
Cyrtoxiphus longipennis Saussure, 1878, Mem. Soc. Geneve, 25:484
Cyrtoxiphus pusillus Saussure, 1878, Mem. Soc. Geneve, 25:486


V. REVIEW OF LITERATURE

Among insects a wide range of sound producing mechanisms are present. In crickets the lower cubital vein of each forewing or tegmen is modified to form a stridulatory file and the antero-internal edge of each forms the scraper. Each tegmen is a movable structure which can open and close and can also be moved up and down. During sound production the tegmina are elevated and the two move laterally across one another forcing the scraper over the file to produce sound. In crickets both the tegmina have equally well developed stridulatory file. But in most of them only the right file is used since in majority of cases the right tegmen covers the left, conveniently designated as R/L position. The females of Gryilloidea do not possess a stridulatory apparatus except in Gryllotalpidae (Baumgartner, 1905, 1910; Malenotti, 1926). In Gryilloidea the normal tegminal position is R/L but theoretically sound can be produced with the inverted position of tegmina L/R. Various experiments on the position of tegmina and the sound production have been conducted by Kreidl and Regen (1905), Lutz (1906), Golda and Ludwig (1958), Stark (1958) and Rakshpal (1960). Kreidl and Regen (1905) observed that the song of L/R Gryllus Campestris (L) is weaker than the
normal song produced by R/L position of tegmina. A similar observation on this species was also made by Keilbach (1935) who also found that in this position it can emit offensive sound. Golda and Ludwig (1958) observed a large number of individuals of *Gryllotalpa gryllotalpa* (L.) and *Acheta domesticus* (L.) and found that in natural conditions a very small number (1/2000) of the individuals have inverted wing position (L/R). Rakshpal (1960) found that almost 4-10% of the individuals of *Acheta* possess L/R position in natural population.

Stärk (1958) mechanically inverted the position of tegmina in *Gryllus bimaculatus* De Geer and found that they regain normal position within five minutes. However, if the reversal is done at an early nymphal stage the majority retains this inverted position and produces songs. He observed further that a subsequent change from L/R to R/L position is resisted by the males and they revert to the L/R position in which they were put at the beginning.

In order to determine the utility of files on both the tegmina Rakshpal (1960) destroyed the file of the right tegmina, in *Acheta veletis* Alex. and Big. and noted that the insects spontaneously change the position of tegmina from R/L to L/R and begin singing again.

Among Orthopterans most of the members of the superfamilies, Tettigoniioidea and Grylloidea employ acoustic signals for intraspecific communication. It has been suggested (Alexander, 1962) that the ancestors of the present day gryllids and tettigoniids might have used both the tegmina for sound production and later diverged as two different superfamilies one having R/L tegminal position and other L/R.

Several important papers have appeared on various aspects of sound production mechanism. Kreidl and Regen (1905) and Lutz and Hicks (1930) showed that each cycle of sound wave corresponds to the impact of the scraper against a tooth of the file. Pierce (1948) has been the first to describe in detail sound production in a variety of animals including insects. He suggested that in crickets:
"As each tooth of the file passes over the scraper, a thrust in one direction is given to the file, and an opposite thrust to the scraper. These thrusts are periodic forces with a frequency determined by the number of impacts per second of the file teeth with the scraper".

He also calculated the number of teeth used in producing a pulse by different crickets and the speed of the scraper over the file.

Alexander (1956, 1960) while working with Nemobius Corolinus/Scudder, Orocharis Saltator Uhler and Oecanthus niveus De Geer found that the emitted frequency varies according to the speed at which the file is swept across the scraper.

In order to determine which part of the tegmen is responsible for generating frequency certain experiments were carried out. Alexander (1956) cut the tegmina of Pterophylla camellifolia (Febr.) in a manner that the stridulatory file and the scraper remained intact. He found that sound was produced and that its frequency was not effected, it was only the intensity which was considerably lowered. Similar observations were made by Walker (1957b) on Oecanthus nigricornis and G. Latipennis. In another paper Walker (1962b) has remarked that the decrease in the dominant frequency at the end of a pulse is due to the teeth being less dense at the
lateral end of the file and when the scraper is near the closing end of the tegmina the tooth strike evidently is less. It may also be due to slowing down of the wing closing movement. According to Dumortier (1963) the tegmen works like an acoustic coupler transmitting the energy produced by tooth strike rate and it is not only the drum but all the tegmen is used for radiating the sound.

Walker (1963) attempted to correlate the number of teeth of the file with the pulse rate of the calling song. He found that the length of the file and the number of file teeth are inversely correlated with the pulse rate. In a latter work Walker and Carlyle (1975) after a long discussion finally came to the conclusion that there is no relation between particular teeth structure and particular features of calling song. Such structures are however of phyletic importance. Nocke (1970) studied the tooth impact rate and frequency of various tegmental parts in Gryllus campestris. Nocke (1971) carried out interesting experiments on Gryllus campestris, G. bimaculatus and Acheta domesticus on the sound radiating tegmental surfaces, particularly the harp region, to find its effect on the intensity of the sound. Bennet-Clark (1970) studied the mechanism of sound production
in mole crickets, *Gryllotalpa vineae* and *G. gryllotalpa*. He found that the fundamental frequency is 3.5 kHz in *G. vineae* and 1.6 kHz in *G. gryllotalpa*. The sound is produced from horn-shaped burrows which are not as resistive acoustic load. He also calculated the mean acoustic power of *Gryllotalpa* and compared with *Gryllus campestris*. Popov (1971) studied the sound production in *Acheta domesticus*. Popov (1972) studied cricket sounds of southern region of USSR and from south-western Tadjikistan (Popov et.al, 1974). Spooner (1973) studied the sound production in a katydid *Cyphoderris monstrosa* Uhler which has a calling song that appears to have Gryllid-like pure frequency in the frequency range typical of tettigoniids. This species produces intense short trills at a frequency of 13 kHz at 25°C. The pulse rate is about 71.4 per second and the trill is produced in about 0.5 to 2.0 seconds. He observed that the males switch the wings regularly while calling, a phenomenon not typical in Grylloidea and Tettigonioidae. He also studied the stridulatory file of both the right and left tegmen. Sismondo (1979) investigated the stridulation and tegminal resonance in the tree cricket *Oecanthus nigricornis* F. Walker. He found that the carrier frequency 3 kHz (at 15°C) to 4.5 kHz (at 32°C) of the song is equal to the teeth impact rate, and under thermal equilibrium the
pulse frequency and the tooth impact frequency are directly correlated. The mechanism underlying the two parameters is not the same as they behave differently to step change in temperature. Tegminal free resonances have been identified in the range 1-6.9 kHz. There is a series of tegminal resonance (from 5.1 kHz to 5.85 kHz) outside the tooth impact frequency. Few individuals stridulate with carrier frequencies in the range of higher tegminal resonance (5.2 kHz to 5.75 kHz). After comparing these data with those on Gryllus he supported the concept of a resonator with continuously variable tuning. Rauf and Aziz (1982) studied the sound production in Gryllodes sigillatus Walker. They found that the song consists of chirps having 3 pulses each produced in a stereotyped manner. The pulse duration ranges from 0.01 to 0.02 seconds. The frequency of the song is 5.7 kHz (at 30°C) and nearly all the teeth are struck in the longest pulse. In a single chirp either the whole of the file, 3/4 or only 1/2 of it, may be used in producing the three types of pulses.

The earliest record of the effect of temperature on chirp rate is provided by the observations of Brooks (1831) on Oecanthus niveus (De Geer). She stated that the
temperature of the air can be estimated by counting the number of chirps of the cricket song. This can be calculated by the formula: \( T = 60 + \frac{(N-72)}{4} \), where \( T \) = temperature in °F and \( N \) = number of chirps per minute. Several workers notably Dolbear (1897) and Bessey and Bessey (1898) proposed their modified formula but Shull (1907) contended that while there is a general relationship between the temperature and the rate of chirping, it yet is not possible to express it by any formula. Many other workers like Allard (1912, 1917, 1929, 1930); Crozier (1924); Pierce (1948); Hallenbeck (1949) and Frings and Frings (1957) investigated the effect of temperature on varying parameters of song. Walker (1957, 1962a, 1962b, 1963, 1969a, 1969b, 1975a, 1975b) has studied the effect of temperature on calling songs of various genera of crickets. In the calling songs of crickets belonging to 20 species representing 7 genera and 5 subfamilies he (Walker 1962a) found that the change in pulse rate with the rise of temperature is constant, secondly the higher the pulse rate at a given temperature, is greater the rate of change in the pulse rate with change in temperature. Thirdly, if the pulse rate produced at any one temperature is known the approximate
rate of change can be predicted by assuming that the pulse rate would be zero at 4°C. The frequency also changes with the change in temperature but is not constant at higher temperatures. The change in frequency (per cent) is always less than the per cent change in pulse rate at a given temperature. Walker (1975a) studied 10 species of Orchehim and found linear relationship between wingstroke rate and the temperature. The coefficient of determination ($r^2$) of the regression line was between 0.75 and 0.99 (average, $r^2=0.93$). The slope of regression line varied from 0.9 to 5.1. The temperature at zero sound production, ($Y=0$) was found/11°C (X ± SD = 10.9 ± 1.9). Similar studies were carried out by Frings and Frings (1957, 1962); Jones (1967); Alexander and Thomas (1959); Alexander (1956, 1968, 1957); Dumortier (1963); Spooner (1964); Heath and Josephson (1970); and Walker et al. (1973).

The reproductive behaviour of crickets, which comprises all the specialized interactions of acoustic behaviour and related responses, has been the focal point of many investigators. These contributions can be grouped under major heading in view of the diversification and the richness of the studies made in this field.
Studies on acoustic communication have been done by Busnel (1955), Alexander (1960, 1967), Haskell (1961); Dumortier, (1963); McIntyre, (1977); Nocke, (1972); Korsunovskaya, (1978) and others. Bell (1980) studied the multimodal communication in the black horned tree cricket Oecanthus nigricornis (Walker).

Perhaps the earliest experiment on phonotaxis of cricket Gryllus campestris was performed by Regen (1913). He used telephone lines to transfer the songs of the male cricket at a distance and found that the females positively reacted to such a device. Several workers have planned interesting experiments to determine the phonotaxis among cricket species.

Zeretsky (1972) concluded that in Scapsipedus marginatus the species-specific character of calling song is the pulse interval pattern. Shuvalov and Popov (1977) found that the minimum pause (100 m sec.) between the chirps of calling song of G. bimaculatus is an important factor. If this interval is further reduced the song has no phonotaxic effect upon female. Cade (1979) found that the females of Gryllus integer and G. veletis when deprived of males exhibit positive phonotaxis 4-9 times more frequent than those previously
provided with males. Rainlender et al. (1981) studied the effects of increase in frequency by adding 10 and 15 kHz to the basic signal band of 5 kHz which resulted in erratic searching behaviour of female crickets. Schmitz et al. (1982) apart from other things emphasized that the phonotaxis increases with the increase in the intensity of the calling song in G. campestris.

Some workers endeavoured to use cricket songs for taxonomic purposes by using audiospectograms analysis (Alexander 1975, in Acheta). Similar taxonomic species determination has been done by Walker (1957) and Leroy (1966) in various crickets. Systematic and behavioural studies on Nemobius fasciatus group has been done by Alexander and Thomas (1959) and three species of Nemobius were separated and identified. Walker (1969a, 1969b, 1973) analysed the cricket songs of three genera and on the basis of which he separated several species.

Responses of crickets to acoustic signalling has been investigated from many different angles by several workers. In Grylloidea a lot of work on acoustic behaviour has been recorded. Haskell (1953) studied the stridulation behaviour of domestic cricket. Walker (1958) observed the acoustic behaviour in tree crickets and Busnel (1953, 1954) in different Gryllidae.
Alexander (1956, 1957, 1958) has studied various types of songs and acoustic behaviour in many species of gryllids. Jones (1966) studied inhibition and excitation in the acoustic behaviour of Pholidoptera griséoaptera and suggested that the chirping may be inhibited or excited by a pacemaker system with its various inputs. The male singing either alone or in groups produce short chirps of 3-4 syllables lasting about 100 m sec. Dambach and Lichtenstein (1978) studied the ethology of Phaeophilacris spectrum Saussure and observed that a single male defends a social group of females against other females. The females perform 2 types of non-stridulatory wing flicking.

Many workers have studied the mating behaviour in gryllids. Pierce (1948) described the mating behaviour in Oecanthinae. The male exhibits some courtship gestures after which the female mounts. It feeds on the matanotal gland of the male. This singing and feeding alternates for about half an hour after which the male extends its abdomen backwards and coitus is effected. Ghouri and MacFarlane (1957) studied the copulation and mating behaviour in house crickets. Khalifa (1949, 1950) studied the mechanism of insemination and sexual behaviour in Gryllus domesticus L. Gabutt (1954) observed the
mating behaviour of *Nemobius sylvestris* (Bosc.). Sexual behaviour patterns and their inheritance were studied by Hormann-Heck (1957) in *Gryllus bimaculatus* and *Gryllus campestris* L. Alexander (1964) studied the evolution of mating behaviour in Arthropods. Alexander (1957) has described song relationship of four species of ground crickets. The same year he published another paper on sound production and associated behaviour in insects. Among gryllids he selected mountain field cricket *Acheta assimilis* in which he described aggressive, courtship and mating behaviour. Alexander (1960) has given a comparative account of sound communication in Orthoptera and Cicadidae. In 1961 he brought out a detailed paper on aggressive, territorial and sexual behaviour in field crickets. Alexander and Thomas (1959) recognized 3 stages of courtship behaviour and in the final stage more or less continuous tegminal rhythm was found to be so similar in *Acheta*, *Gryllus* and *Gryllodes sigillatus* that a common origin has been suggested. Mays (1971) studied the mating behaviour of 10 species of nemobiinae crickets of the genus *Hygronemobius*, *Nemobius* and *Pteronemobius*. Spooner (1972) observed courtship behaviour in *Falcicula hebardi* Rehn, but he did not report the copulation, though some observations were made on post copulatory behaviour. Walker (1973) observed the courtship in his species *Anurogryllus arboreus*. He found that the male produces 5-20 minutes
Song during the end-to-end coupling after the spermato- 
phore tube has been inserted—a feature which according 
to him has not been reported in any other cricket. Loher 
and Renč (1978) studied the mating behaviour of Teleogryllus 
commodus and its central and peripheral control. Sakaluk 
and Cade (1980) studied the female mating frequency and 
progeny production in Acheta domesticus and Gryllus integer. 
They found that doubly mated females produced more off­ 
springs than singly mated in both the species. The females 
often eat the externally attached spermatophore during 
guarding for nutrition. Repeated mating ensures insemination.

Singing behaviour of males and their responses have 
been studied by many workers. Paul and Walker (1979) 
studied the arboreal singing in Anurogryllus arboreus. 
They described various singing locations in terms of 
the nearest neighbour relationship of the field crickets 
Gryllus integer, G. veletis and Teleogryllus oceanicus 
and found that males maintain an inter­ male distance 
from a conspecific singer. Cade and Otte (1982) 
studied the alternation calling and spacing in Acantho­ 
gryllus fortipes and observed that the male calls in
the silent inter-chirp interval of the neighbour's song. He also demonstrated experimentally that the males aggregate spatially maintaining distance during alternation. Greenfield and Shaw (1983) identified different kinds of chorusing and constructed separate terminology for each category in Orthoptera. Kreasky (1972) demonstrated that Gryllus species shows positive response to the near UV region of the spectrum and this may be the reason why crickets are attracted to mercury vapour lamps.
VI- MECHANISM, PHYSICAL NATURE OF SONGS PRODUCED AND RELATED RESPONSES

1. Gryllus mitratus Burmeister

A. Mechanism and physical nature of songs

Gryllus mitratus lives in grassy fields, shrubs, underground burrows and beneath the stones and dry leaves. It prefers humid conditions. It starts calling in the evening and sings for about 5-7 hours at night. The songs are commonly heard in the months of March till late April and from June to October. Few individuals were heard singing in the day time during early November. Large numbers of these crickets are attracted towards mercury vapour lamps during rainy season.

Structure of the stridulatory file

In G. mitratus the stridulatory file of both the tegmina are well developed. In the file of the right tegmen (Pl.IV-10) all the teeth are slightly curved and directed mesally, except at the outer end which are relatively straight. The length of stridulatory file ranges from 4.26-4.72 mm, average being 4.45 mm. The number of teeth varies from 252-283 and the average is 264 teeth (Table 4). The length of an individual file is 4.29 mm, bearing 264 teeth. The tooth density
Table 4

Average length of the file and average number of file teeth of gryllids species

<table>
<thead>
<tr>
<th></th>
<th>LENGTH OF FILE (mm)</th>
<th>NUMBER OF FILE TEETH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Range</td>
</tr>
<tr>
<td>Gryllus mitratus</td>
<td>4.45</td>
<td>4.26 - 4.72</td>
</tr>
<tr>
<td>Gryllus bimaculatus</td>
<td>4.71</td>
<td>4.47 - 5.15</td>
</tr>
<tr>
<td>Gryllus domesticus</td>
<td>2.81</td>
<td>2.58 - 3.01</td>
</tr>
<tr>
<td>Gryllodes sigillatus</td>
<td>2.09</td>
<td>1.92 - 2.26</td>
</tr>
<tr>
<td>Pteronomobius fascipes</td>
<td>0.74</td>
<td>0.62 - 0.84</td>
</tr>
<tr>
<td>Araxipha longipennis</td>
<td>0.74</td>
<td>0.69 - 0.82</td>
</tr>
</tbody>
</table>

Average of 10 files of each species studied
is highest at the inner end of the stridulatory file (146.59 teeth/mm) and lowest at the outer lateral end (30.39 teeth/mm). Table 5, shows the characteristics of the individual file of the right tegmen. The teeth at the inner end of the stridulatory file are very small and progressively increase in size towards its outer end where they are relatively widely spaced.

Physical nature of songs

On various occasions crickets produce a variety of songs. They have been classified according to the behaviour patterns and the circumstances which are conducive to the production of the songs. The basic acoustical unit of the song is the pulse. A group of pulses is termed as chirp which is defined by Broughton (1963) as the shortest unitary rhythm that can be readily distinguished as such by the unaided human ear. A trill as defined by Walker (1957) is a series of pulses emitted without interruption for several seconds indeed for several minutes. It has generally high pulse rate and the succession of repeated sounds are resolvable by the human ear. The number of sound waves produced in a second is termed as frequency and is represented in kHz. The loudness or intensity of the sound produced is measured in terms of decibels (dB). Different types of songs and the terminology of Faber (1953) as modified by Haskel (1964) has been adopted in the following description.
<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Right Legmen*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the file (in.)</td>
<td>4.29</td>
</tr>
<tr>
<td>Total teeth in file</td>
<td>264</td>
</tr>
<tr>
<td>Tooth density** (teeth/in.) as</td>
<td></td>
</tr>
<tr>
<td>per 18 teeth of the file length</td>
<td>146.59</td>
</tr>
<tr>
<td></td>
<td>144.73</td>
</tr>
<tr>
<td></td>
<td>133.74</td>
</tr>
<tr>
<td></td>
<td>121.22</td>
</tr>
<tr>
<td></td>
<td>105.14</td>
</tr>
<tr>
<td></td>
<td>97.52</td>
</tr>
<tr>
<td></td>
<td>77.13</td>
</tr>
<tr>
<td></td>
<td>69.3</td>
</tr>
<tr>
<td></td>
<td>59.86</td>
</tr>
<tr>
<td></td>
<td>52.58</td>
</tr>
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<td>48.13</td>
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<td>44.78</td>
</tr>
<tr>
<td></td>
<td>41.23</td>
</tr>
<tr>
<td></td>
<td>40.73</td>
</tr>
<tr>
<td></td>
<td>38.64</td>
</tr>
<tr>
<td></td>
<td>38.57</td>
</tr>
<tr>
<td></td>
<td>37.99</td>
</tr>
<tr>
<td></td>
<td>30.39(9)</td>
</tr>
</tbody>
</table>

* Stridulatory file of the right tegmen is used.

** Tooth density listed starts from the inner end of the stridulatory file at the top of the column. The last numeral is based on 9 teeth as shown in the parenthesis.
Table: 6

Pulse duration in 5 pulse/chirp calling sing of *Gryllus mitratus* Burmeister at 35°C.

<table>
<thead>
<tr>
<th></th>
<th>I (Sec)</th>
<th>II (Sec)</th>
<th>III (Sec)</th>
<th>IV (Sec)</th>
<th>V (Sec)</th>
<th>Average duration of pulse in Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0162</td>
<td>0.0189</td>
<td>0.0252</td>
<td>0.0245</td>
<td>0.0309</td>
<td>0.0231</td>
</tr>
<tr>
<td>±</td>
<td>±0.0043</td>
<td>±0.0045</td>
<td>±0.0061</td>
<td>±0.0051</td>
<td>±0.0071</td>
<td>±0.0057</td>
</tr>
</tbody>
</table>

*†* Standard deviation

data based on 10 replicates
a) Calling song: The calling song of *G. mitratus* is characterized by pulses ranging from 3-9 in different chirp. The interval between the chirps and the duration of the pulses is stereotyped in a song depending on certain environmental factors. The average pulse duration in 5 and 6 pulses per chirp in a song is 0.0231 ± 0.0057 sec and 0.0231 ± 0.0034 sec respectively (Table 6,7) and in a 7 pulses song the average comes to 0.0254 ± 0.0044 sec (Table 8).

It has been observed that with a change in temperature the chirp rate is altered and consequently the pulse rate also changes. The pulse rate as shown in Text/- 3 is higher at higher temperature. The calculated value of regression line is \( \hat{Y} = -16.24 + 1.04 \times \) (\( \hat{Y} \) = expected pulses per second; \( X \) = degree Celsius).

The calculated value of 0 pulse/sec comes to 15.5 °C. Sonograms at different temperatures (Pl.VIII-26-31) show that the frequency does not appreciably change with varying temperature and that pulse duration, chirp duration, inter-chirp interval and inter-pulse gap decrease with the rising temperature.

Another feature of the *G. mitratus* is the production of slow and fast calling song under experimental conditions at a given constant temperature (Pl.VI-16 and 17).
Table: 7

Pulse duration in 6 pulse/chirp calling song of *Gryllus mitratus* Burmeister at 29°C.

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>Average pulse duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
</tr>
<tr>
<td>0.0107</td>
<td>0.0235</td>
<td>0.0235</td>
<td>0.0274</td>
<td>0.0240</td>
<td>0.0233</td>
<td>0.0231</td>
</tr>
<tr>
<td>±0.0010</td>
<td>±0.0049</td>
<td>±0.0007</td>
<td>±0.0032</td>
<td>±0.0018</td>
<td>±0.0008</td>
<td>±0.0034</td>
</tr>
</tbody>
</table>

* Standard deviation
data based on 10 replicates
Table 8

Pulse duration of 7 pulses/chirp calling songs of *Gryllus mitratus* at 32°C.

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>Average pulse duration (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>0.0198</td>
<td>0.0123</td>
<td>0.0245</td>
<td>0.0275</td>
<td>0.0275</td>
<td>0.0283</td>
<td>0.0283</td>
<td>0.0251</td>
</tr>
<tr>
<td>SD</td>
<td>±0.0006</td>
<td>±0.0019</td>
<td>±0.0008</td>
<td>±0.0013</td>
<td>±0.0026</td>
<td>±0.0030</td>
<td>±0.0003</td>
<td>±0.0014</td>
</tr>
</tbody>
</table>

+ Standard deviation

data based on 10 replicates
Text Fig. 3

Effect of temperature on pulse rate in Gryllus nitratos.
Thus the calling of this species may be considered as slow and fast, the slow song having longer chirps (6-7 pulses/chirp) while the fast one was found to have shorter chirps (3-6 pulses/chirp). At 30°C the chirp rate is 1-4/sec depending upon the nature of song (slow or fast). The alternate singing in nature in solitary males is recorded during early and late nights. In the earlier hours of night the alternation of chirps is more common. This phenomenon has been discussed more fully under responses. The frequency of the calling song ranges from 4.7 to 5 kHz. The mean frequency is 4.812 kHz at 30°C (Pl.VI-17). During calling song the tegmina are raised at an angle of 45° in respect of the longitudinal axis of the body. The peak intensity is 112 dB at 12 cm away from the calling male.

B) Courtship song: The courtship song is composed of an initial 4-6 pulses grouped like a chirp followed by a trill (Chirp+trill). This alternating chirp-trill is continued for a period of time particularly in the presence of a female when the male is sexually receptive (Pl.VI-18). It is considered here as a precourtship song which may be termed as luring type to induce the female for copulation.
This song consists of 4-6 pulses in chirp and 50-100 pulses in the trill. This complex (Chirp + trill) is produced 1-2 times in a second. The average length of the initial chirp is $0.173 \pm 0.036$ sec (range 0.117-0.212 sec). The length of the pulse train is $0.615 \pm 0.513$ sec (range 0.133-1.88 sec). Pulse duration is $0.0294 \pm 0.0052$ sec (range 0.0229-0.0358 sec) and $0.0135 \pm 0.0021$ sec (range 0.0063-0.0157 sec) in chirp and trill respectively (Table 9). The average gap between successive complexes is $0.189 \pm 0.09$ sec (range 0.078-0.353 sec) (Pl.VI - 18). In the event of positive response by the female the song is altered into a pure trill having gaps in between, while pulse duration remains the same as in the above song (Pl.VI - 19).

The courtship song of this species is similar to the calling song of *Teleogryllus commodus* (Loher and Rence, 1978) where the chirp contains 6 pulses and the trill between 10 and 90 pulses. A characteristic feature of the individual pulse of the trill portion is a small gap in the individual pulse. This can be explained by assuming that at the time of trill production the tegmina are kept very low at an angle of about 180°. During closing, the scraper moves over the downwordly projected teeth up to the outer end of the file, thereafter, for a short pause it moves again during the opening motion of the tegmina and produces the second
Table: 9
Pulse duration in different types of courtship pulse of *Crilllus nitratite*.

<table>
<thead>
<tr>
<th></th>
<th>Average pulse duration (Sec)</th>
<th>S.D. (Sec)</th>
<th>Range (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Click before chirp pulses</td>
<td>0.0051</td>
<td>0.0046</td>
<td>0.0047 - 0.0059</td>
</tr>
<tr>
<td>Chirp like group of pulses</td>
<td>0.0054</td>
<td>0.0052</td>
<td>0.0229 - 0.0358</td>
</tr>
<tr>
<td>Pulse train (Trill like)</td>
<td>0.0129</td>
<td>0.0021</td>
<td>0.0063 - 0.0157</td>
</tr>
<tr>
<td>Full courtship pulses</td>
<td>0.0161</td>
<td>0.0011</td>
<td>0.0151 - 0.0179</td>
</tr>
</tbody>
</table>

+ Standard deviation
data based on 10 replicates
component of the pulse. But this explanation does not hold true when we scrutinize this intrapulse gap in the oscilogram where this so-called gap is actually filled up by nondescript continuous week signals (Pl.XX-77). The central frequency in the chirp is 4.8 kHz and in trill pulses it is 4.5 kHz (Pl.VI-18 and 19). Pulses of very short duration precede each chirp and last for about 0.0051 sec having the central frequency of 5.1 kHz.

C) **Aggressive song:** This is primarily a warning song produced by a male on the intrusion of another in its territory and also at the time of interruption of courtship by another male. This song is stridulated in group chirps whose rate depends upon the reaction of intruder. The song lasts for 2-3 minutes. On receiving an alarming response from the intruder a fierce fight ensues resulting in the mutilation of either combatant. The chirp length in the song is 0.276 ± 0.549 sec. The pulse duration is 0.0365 to 0.0313 ± 0.0086 sec (Table 10). Each pulse consists of two parts of different frequencies. Their duration is 0.2050 ± 0.0028 sec and 0.0166 ± 0.0013 sec respectively. The frequency of the offensive song is variable, depending upon the speed of movement of
Comparison of the pulse of the heart between the control and the experimental groups.

<table>
<thead>
<tr>
<th>Group</th>
<th>Sec</th>
<th>Sec</th>
<th>Sec</th>
<th>Sec</th>
<th>Sec</th>
<th>Sec</th>
<th>Sec</th>
<th>Sec</th>
<th>Average (Sec) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0.0360 ± 0.0027</td>
<td>0.0392 ± 0.0045</td>
<td>0.0392 ± 0.0030</td>
<td>0.0396 ± 0.0042</td>
<td>0.0383 ± 0.0071</td>
<td>0.0313 ± 0.0086</td>
<td>0.0365 ± 0.0033</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experimental</td>
<td>0.0329 ± 0.0067</td>
<td>0.0407 ± 0.0050</td>
<td>0.0404 ± 0.0051</td>
<td>0.0361 ± 0.0063</td>
<td>0.0404 ± 0.0072</td>
<td>0.0135 ± 0.0040</td>
<td>0.0156 ± 0.0050</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the tegmina and their elevation from 30°-50°. The frequency varies from 4-6 kHz. The central frequencies are 5.2 kHz and 4.136 kHz in the two parts of a pulse (Pl.VI -20, Pl.VII -25).

**Mechanism of song production**

The calculated number (n) of sound waves varies per pulse in different songs of *G. mitratus* (Table II). The value of n=111 in a 5 and 6-pulse calling song, whereas in a 7 pulse song the value of n is 122 which means that 42% and 46% of the total number of teeth in the file have been used respectively.

The courtship song consists of 3 types of component pulses which vary in duration and frequency. The initial short pulses are produced by 26 teeth followed by pulses of a chirp each produced by 141 teeth. The pulses of the final trill are produced by 60 file teeth. It means that the click-chirp-trill combination utilizes 10%, 53% and 23% teeth of the total file respectively. The varying frequency is suggestive of the fact that the speed of the scraper over the file also varies in these pulses.

The aggressive song consists of compound pulses each having two parts. It seems that a two step closure
Table: 11

Calculated value of $n$ - The number of sound waves emitted by *Gryllus mitratus* Bruneister in pulses of different songs.

<table>
<thead>
<tr>
<th>Song</th>
<th>Average pulse duration $t$ in Sec.</th>
<th>Average frequency in Cycles/Sec.</th>
<th>$n$</th>
<th>Percent teeth used*</th>
<th>Average percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calling 5 pulse</td>
<td>0.0231</td>
<td>4800</td>
<td>111</td>
<td>42%</td>
<td></td>
</tr>
<tr>
<td>6 pulse</td>
<td>0.0231</td>
<td>4800</td>
<td>111</td>
<td>42%</td>
<td></td>
</tr>
<tr>
<td>7 pulse</td>
<td>0.0254</td>
<td>4800</td>
<td>122</td>
<td>46%</td>
<td></td>
</tr>
<tr>
<td>Courtship short Initial pulses</td>
<td>0.0051</td>
<td>5100</td>
<td>26</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Chirp like pulses group</td>
<td>0.0294</td>
<td>4800</td>
<td>141</td>
<td>53%</td>
<td>28%</td>
</tr>
<tr>
<td>In long pulse train (trill)</td>
<td>0.0135</td>
<td>4500</td>
<td>60</td>
<td>23%</td>
<td></td>
</tr>
<tr>
<td>Aggressive song</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>first part of the pulse</td>
<td>0.0205</td>
<td>5200</td>
<td>107</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>second part of the pulse</td>
<td>0.0166</td>
<td>4136</td>
<td>69</td>
<td>26%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>175</td>
<td></td>
<td></td>
<td>66%</td>
<td>66%</td>
</tr>
</tbody>
</table>

* taking 264 total teeth in the representative file.
of tegmina produces the pulse. The speed of scraper over the file in the first step is faster than in the second part. The number of sound waves in the first half is 107 and in the second half it is 69. The scraper slows down a bit and changes the speed as it produces the second part of the pulse. The total number of teeth used in this pulse is about 175 teeth. The values of \( n \) given above have been calculated (Table II) and confirmed by oscillograms (Pl.XIX and XX - 73-79).

B. Song related responses

In *G. mitratus* the males have variable chirp rate in calling. In day time when a single male stridulates the chirp rate is 35 chirps/minute at 23°C. When two males sing each delivers an alternate chirp about half as fast (Pl.VII-23; and Text Fig-4). This has been observed during early evenings in summer when they are within hearing range (7-10 metres) and during November and December in the late evenings. Two males sometimes synchronize their chirps when they are close enough but outside visual range. The leader initiates the call which is partially overlapped by the other (Pl.VIII -32).

In a collection made under mercury bulb it was found that the females far outnumber the males (40:4). In such an assembly occasionally courtship songs were
Diagrammatic illustration of  

A—single male calling sequence.  

B and C—alternating sequence.  

Modified from sonograms of  

*Gryllus mitratus*. 

Text Fig. 4
heard. Similar songs were also heard in day time when nights became cooler as in November. No mating could be observed in the field conditions.

Under laboratory conditions a few males (five) when put together, confronted each other by the antennae and assumed a threatening posture by repeatedly jerking their bodies. One may retreat quickly or in the event of a challenge the two grapple each other by their mandibles and kick by producing loud chirps. This may result in the mutilation of the antennae and legs. The antennae play an important role in tactile communication. If they are lost the cricket is unable to defend itself well. The defeated party retreats. In crickets the aggressive sound is triggered by tactile or auditory contact with other males. (Haskell, 1964). In field crickets, this behaviour is associated with the territory of the males (Alexander, 1961). This type of behaviour is evident on the first day in a group of males confined in a glass jar but as the time passes they learn to live in peace and hardly any combat occurs after 3-4 days, though a few aggressive calls may be heard. Another peculiarity of this species is that when such a peaceful atmosphere is established in the jar one male dominates and starts
singing courtship songs as if a female is around. The song continues for more than one hour. No offensive song was heard after the onset of courtship behaviour in all the 10 jars maintained for the purpose. After the courtship song they disperse and stand still in different positions in the jar. Some may however, start calling and others courtship songs.

As regards the male to female responses the latter are attracted towards the male as they hear the calling song and begin to antennate. Rence and Loher (1977) have stated that while morphologically antennae of both sexes are similar but there is indication of the presence of sex recognition pheromones of chemo-tactile nature on the antennae. After antennation the male produces courtship song. An unresponsive female detests the male antennal touch. In such case the male reverts to calling song alternating with the courtship song. In case of positive response the male starts precourtship song which may sometimes last for 25-30 minutes after which full courtship song starts. The sequential order of events is as follows: Before mating both sexes start moving their hind legs over the abdomen. The female touches the cerci of the male with her antennae. Before actual mounting the sternal part of the female abdomen moves up and down. The male produces 6-8 long trills of full courtship song and vigorously vibrates the antennae which attract the female closer. The male then turns
backward so as to bring its abdomen in front of the female head. The female then mounts the male (Pl.XXVI-112). The cerci move rhythmically in both the sexes. After a minute and a half the abdomen of both start vibrating in unison and continue for about 45 sec during which genitalia are adjusted. The antennae of the male are laterally extended and their tips move in a manner so as to describe circles. The female remains at rest throughout. The antennal movements stop marking the end of copulation after which the pair disengages. The reddish, yellow spermatophore is carried by the female as it remains attached to the base of cerci (Pl.XXVI-113, 114). The sexually receptive pair can copulate twice within half an hour and may still remain receptive. It seems that the adults can copulate many times over depending upon the sexual vigour of the sexes.

After the separation, the male closely guards the female and occasionally touches its abdomen by the antennae (Pl.XXVI-113). It produces long chirps followed by gaps of silence. The guarding is over after 5-7 minutes. If an intruder disturbs during guarding fierce fight follows (Pl.XXVII-117).

At 25°C the total time of copulation was 8 minutes and 5 sec. The length of the song was 47 seconds. The male moves cerci at a rate of 2/sec for 5 minutes. The bodies of the pair vibrated for 61 seconds.
2. *Gryllus bimaculatus* De Geer

A. Mechanism and physical nature of songs

Observations on *Gryllus bimaculatus* spread over five consecutive years at the field station have shown that curiously this species starts calling song from the first week of January every year. The singing continues till late September or early October during which the population of singing males fluctuates. The song can be heard at a distance of 40-50 metres. The males never aggregate in the fields but prefer singing at night in isolation from places high up like hollows in the trees or under stones, burrows etc. to avoid exposure to the ravages of the predators. Occasionally during monsoon months when hideouts get flushed with water they are seen in human dwellings, particularly at night when they leisurly sing. During November and December when the field temperature falls this species often migrates towards a moderate temperature area in which case their singing schedule and duration also changes. Morning and evening songs are now generally heard. It has been observed that individuals of *G. bimaculatus* call in the field for about 2 or 3 days at one site and later move to other places. Courtship songs have been heard in the evenings and nights but actual courtship could not be observed under field conditions. This species is greatly attracted to mercury vapour lamps where the females always
Structure of the stridulatory file

In *G. bimaculatus* the stridulatory files of both the tegmina are well developed but only the file of the right tegmen (Pl.1V-11) is used in sound production. When the position of the tegmina is experimentally reversed to L/R position in anaesthetized males, (n=20) they assumed anormal position within 4-5 min after regarding consciousness. The file length varies from 4.47-5.15 mm (average 4.71 mm). The number of teeth varies from 147.162 (average is 152 Table 4). The length of a representative file is 5.08 mm. The total number of teeth is 152. In the middle of the file teeth are larger and less dense (23.08 teeth/mm). The density is 69.23 teeth/mm at the inner and 39.99 teeth/mm at the outer end of the file (Table 12).

Physical nature of songs

a) Calling song:

The calling song in this species is characterised by the number of pulses per chirp, inter-pulse and inter-chirp interval and their overall duration. At 30°C, in a 3 pulse/chirp song, the pulses are 0.0161-0.0181 sec long (Average, 0.0168 sec) and 0.0092-0.0102 sec apart. The average chirp duration is 0.0705 ± 0.0051 sec (Table 13). In 4 pulse/chirp song at 30°C, the
Table 1:

Characteristics of the stridulatory file of the male of *Gryllus bimaculatus* De Geer

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Right Tegmen*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the file (mm)</td>
<td>5.08</td>
</tr>
<tr>
<td>Total teeth in file</td>
<td>152</td>
</tr>
<tr>
<td>Tooth density** (teeth/mm) as per 15 teeth of the file length.</td>
<td>69.23, 40.91, 33.33, 28.12, 24.32, 23.08, 23.08, 24.99, 29.03, 34.62, 39.99 (2)</td>
</tr>
</tbody>
</table>

* Stridulatory file of the right tegmen is used.

** Tooth density listed starts with the inner end of the stridulatory file at the top of the column. The last numeral is based on 2 teeth as shown in parenthesis.
Table: 13

Pulse duration and silent period between pulses in 3 pulse chirp calling song of *Gryllus bimaculatus* De Geer at 30³C

<table>
<thead>
<tr>
<th>Pulse</th>
<th>Silent period</th>
<th>Pulse</th>
<th>Silent period</th>
<th>Pulse</th>
<th>Chirp duration</th>
<th>Average pulse duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Sec</td>
<td>I</td>
<td>Sec</td>
<td>II</td>
<td>Sec</td>
<td>III</td>
</tr>
<tr>
<td></td>
<td>0.0162</td>
<td></td>
<td>0.0181</td>
<td></td>
<td>0.0161</td>
<td>0.0705</td>
</tr>
<tr>
<td>±0.0006</td>
<td>±0.0008</td>
<td></td>
<td>±0.0050</td>
<td></td>
<td>±0.0051</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0092</td>
<td></td>
<td>0.0102</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>±0.0006</td>
<td></td>
<td>±0.0002</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*± Standard deviation
data based on replicates*
pulses are 0.0178-0.0186 sec long (Average, 0.0184 sec) and 0.0094-0.0118 sec apart. The pulse rate is 15 pulses/sec at 30°C. The average chirp duration is 0.1050 ± 0.0020 sec (Table 14). Sonograms (Pl.IX-33 and 34) show that the pulse is composed of a basic frequency 5.3 and 5.5 kHz respectively.

The overall sound intensity of a cricket song as reported by (Nocke, 1971) depends on the resonance properties of the tegmen or a part of it, such as the 'harp' and the 'mirror'. In G. bimaculatus the loudness of long is attributable to the degree by which the tegmina are raised. During calling they are held at 45° or more over the abdomen resulting in a peak intensity of sound of 115dB/5 cm. When they are cut in a manner that the scraper and the file remain intact (Text fig. 5) the intensity of sound is reduced though the carrier frequency remains the same (Pl.X-39). The effect of temperature on pulse rate is shown in Text Fig.6. The equation of the linear regression line is Y = -4.18 + 0.80 X. 0 Pulse/sec comes to 5.18°C celsius.

B) Courtship Song

The courtship song contains primary and secondary songs in respect of singing sequence in time. The pulses of primary courtship song are irregular varying in
Table 1

Pulse duration and silent period in the 4 pulses/chirp calling song of *Gryllus bimaculatus* De Geer at 30°C.

<table>
<thead>
<tr>
<th></th>
<th>Silent period</th>
<th>Pulse</th>
<th>Silent period</th>
<th>Pulse</th>
<th>Silent period</th>
<th>Pulse</th>
<th>Chirp duration</th>
<th>Average pulse duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Sec.</td>
<td></td>
<td>Sec.</td>
<td></td>
<td>Sec.</td>
<td></td>
<td>Sec.</td>
<td>Sec.</td>
</tr>
<tr>
<td></td>
<td>0.0186</td>
<td></td>
<td>0.0184</td>
<td></td>
<td>0.0112</td>
<td></td>
<td>0.0178</td>
<td>0.0118</td>
</tr>
<tr>
<td></td>
<td>±0.0011</td>
<td></td>
<td>±0.0004</td>
<td></td>
<td>±0.0012</td>
<td></td>
<td>±0.0008</td>
<td>±0.0007</td>
</tr>
<tr>
<td>±</td>
<td>Standard deviation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data based on 10 replicates</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Text Fig. 5

Diagrammatic representation of the ventral view of right tegmen of *Gryllus bimaculatus*. Broken line represents the part from where the tegmen was cut. P. file and, D. drum.
Text Fig. 6

Effect of temperature on pulse rate in *Gryllus bimaculatus*.
duration from 0.0033 - 0.0131 sec (Average, 0.0084 ± 0.0042 sec; Table 15). The frequency sweep is 4-6 kHz (Pl.IX-35 and 36). This is followed by secondary courtship song which consists of a click followed by irregular transient pulses. The clicks vary from 0.0037 - 0.0080 sec (Average 0.0050 ± 0.0015 sec) and the transient pulse duration varies from 0.0014 - 0.0061 sec (Average, 0.0029 ± 0.0018 sec; Table 15). The frequency varies from 0.789 - 7.305 kHz in clicks and 3.554 - 6.092 kHz in transient pulses (Pl.IX-37). The elytra are raised at about 25° degrees.

c) Aggressive song

It is generally produced in the presence of an intruding male cricket. The individual chirps contain 6-10 pulses each. The chirp rate is about 1-3 chirps/sec (Average, = 1.96). The inter-chirp duration varies from song to song (0.1714 - 0.573 sec; Average, 0.3647 ± 0.1168 sec) depending upon the reactions of the intruder. The pulse duration is 0.0194 ± 0.0019 sec and the pulses are separated by a silent period of 0.0167 ± 0.0029 sec in the chirps (Table 16). The frequency of the aggressive song varies from 4.738 - 5.161 kHz (Average 5.022 ± 0.1118 kHz; Pl.X-38). The elytra are held at 45° - 50° during the production of this song.
Pulse duration in pulse of courtship song of *Gryllus bimaculatus* De Geer at 30°C. Variation is given in parenthesis.

<table>
<thead>
<tr>
<th>Average duration of Primary courtship pulse</th>
<th>Secondary Courtship Sing</th>
<th>Average duration of Clicks (transients)</th>
<th>Average duration of short pulses</th>
<th>Period between one click to the next</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec (0.0033-0.0131)</td>
<td>Sec (0.0037-0.0080)</td>
<td>Sec (0.0014-0.0061)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0064</td>
<td>0.0050</td>
<td>0.0029</td>
<td>0.2790</td>
<td></td>
</tr>
<tr>
<td>±0.0042</td>
<td>±0.0015</td>
<td>±0.0018</td>
<td>±0.0278</td>
<td></td>
</tr>
</tbody>
</table>

Standard deviation data based on 10 replicates.
Table: 16

Pulse duration and other parameters of offensive
(Aggressive) song of *Gryllus bimaculatus* De Geer

<table>
<thead>
<tr>
<th>Pulses in Chirp</th>
<th>Average chirp rate</th>
<th>Average quiescent interpulse period</th>
<th>Average silent period</th>
<th>Average pulse duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chirp/Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
</tr>
<tr>
<td>6 - 10</td>
<td>1.96</td>
<td>0.36/4.7</td>
<td>0.0167</td>
<td>0.0194</td>
</tr>
<tr>
<td></td>
<td>+0.1168</td>
<td>+0.0029</td>
<td>+0.0019</td>
<td></td>
</tr>
</tbody>
</table>

† Standard deviation

data based on 10 replicates
Mechanism of song production

The number of sound waves \( n \) in 3-pulse calling song is 89 and in the 4-pulse calling song it is 101. As there are 152 teeth in a representative file the percentage of teeth used comes to 58% and 66% respectively (Table 17).

In the courtship songs three types of pulses of varying duration and frequencies are present. The number of sound waves or the number of file teeth used \( n \) per pulse in this song is 42, 20 and 14 in the primary pulses, clicks and short pulses (transients) respectively. In these pulses 28%, 13% and 9% of the file teeth (Average, \( \bar{X} = 0.16, 16\% \)) are used respectively. From the above it is evident that the number of file teeth used and the speed of the scraper both change in the production of these pulses.

In the aggressive song it appears that 97 file teeth are used per pulse which amounts to about 64% of the file teeth used. The values of \( n \) given above are confirmed by Oscillograms (Pl. XXI - 81-85)
Table: 17

Calculated value of *n* = the number of sound waves emitted by *Gryllus bimaculatus* different songs.

<table>
<thead>
<tr>
<th>Song</th>
<th>Average pulse duration in Sec.</th>
<th>Average central frequency cycles Sec.</th>
<th>n. fxt</th>
<th>Percent teeth used*</th>
<th>Average percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calling Song</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 pulse</td>
<td>0.0168</td>
<td>5300</td>
<td>89</td>
<td>58%</td>
<td>62%</td>
</tr>
<tr>
<td>4 pulse</td>
<td>0.0184</td>
<td>5500</td>
<td>101</td>
<td>66%</td>
<td></td>
</tr>
<tr>
<td>Courtship Song</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary pulses</td>
<td>0.0084</td>
<td>5000</td>
<td>42</td>
<td>28%</td>
<td></td>
</tr>
<tr>
<td>Clicks</td>
<td>0.0050</td>
<td>4047</td>
<td>20</td>
<td>13%</td>
<td>16%</td>
</tr>
<tr>
<td>Short pulses transients</td>
<td>0.0029</td>
<td>823</td>
<td>14</td>
<td>9%</td>
<td></td>
</tr>
<tr>
<td>Aggressive Song</td>
<td>0.0194</td>
<td>5022</td>
<td>97</td>
<td>64%</td>
<td>64%</td>
</tr>
</tbody>
</table>

* taking 152 total teeth in the representative file
B- Song related responses

In the laboratory when several males (5-7) are put together in a jar fighting invariably ensues and they stop producing song. After sometime one starts calling again. Any interruption in calling leads to the production of aggressive chirps, which never exceed 2 min during which they start fighting. The weaker ones gradually withdraw and the stronger one establishes its dominance. Fighting leads to injuries of the body parts.

Rate of Cannibalism is very high in this species. The antennae are torn first then the posterior abdomen is severely injured. Both the hind legs are eaten and finally the entire abdomen (Pl.XXVII-118). About 80% of the individuals are thus eaten away within a period of 6-7 days. Interestingly, a male thus mutilated may sometimes keep on singing. In view of the high rate of mortality due to fighting, a few pieces of folded papers were dropped into some jars. It was noticed after a short while that most of the weaker crickets moved into these folds and only one of them apparently took over the entire territory. Subsequent observations confirmed that this one proved to be a dominant male.
It was larger in size and looked stouter than other inmates. The dominant male did produce calling songs at will without any interference. If however, any other ventured to produce any song from the hideout it was immediately spotted and attacked. Further it was observed that the calling song if continued for longer period of time a spermatophore becomes visible and the calling song changes into a courtship song. Perhaps as a response to this courtship song some weaker males may come nearer the dominant male and begin to mount and dismount like a female. It could not be established with certainty as to which stimulus, tactile or otherwise, triggers this behaviour.

In the laboratory when a laboratory reared virgin female is introduced in a jar containing a calling male it was found that as the male senses her presence it stops calling and comes closer. Both now begin to antennate. After a while, the male starts courtship song of low intensity (60 db|8 cm). The duration of courtship song is 15 - 30 sec. While the male keeps on singing, he orientates himself in such a way that abdomen faces the head of the receptive female. He then retraces steps to facilitate ride by the female. Meanwhile the spermatophore of the male protrudes and
the sternal part of the female abdomen moves up and down. During mounting the genitalia are adjusted and the antennae of the pair make frequent contacts. The cerci of both the sexes remain in constant motion. The copulation lasts for 28-35 sec during which the spermatophore is transferred to the female genitalia. Sometimes a post copulatory chirp is produced. After the female dismounts the male closely guards the female, despite this in a few cases the female was found devouring the spermatophore with the help of her hind leg (Pl. XXVI-115). In such a situation the mating may be repeated. Guarding may be taken as an adaptation to ensure fertilization.

In case the female is not receptive the male does not produce courtship song and withdraws. It appears from this behaviour that the female provides some stimulus which initiates a response leading to the production of courtship song. Hörmann Heck (1957) has specified that in G. bimaculatus an olfactory emission from the female seems to trigger the courtship song in the males.

Further it has also been observed that a pair which has not been allowed to copulate for a considerable period (20 - 25 days) when allowed to meet the female invariably mounts without being lured by courtship song.
During field observations a songster *G. hemiculatus* was located in a burrow whose sound was appreciably louder in a particular direction. Curiously it gradually became weaker as the author moved a few paces to the left or the right of this 'beam'. This cricket was brought to the laboratory for experiments. As it started calling in a large jar a cardboard tunnel about 8 cm long and 2.5 cm in diameter was improvised and placed inside. It readily moved in but did not sing. Same evening while calling it was found to have rejected the tunnel and was sitting outside assuming an unusual posture. The fore legs were grounded straight and the abdomen was inclined downwards at an angle of 45° to the bottom of the jar, while the tegmina and anterior part of the body were held parallel to it. (Pl. XXVII-113).

The same experiment was repeated with 10 individuals of the same species and the results were characteristically the same in each case. The average height of the tegmina from the ground level was 1.7 cm which is approximately 1/4 of the wave length produced at 5 kHz. From the above observations it was argued that since the sound could only be effectively transmitted through the mouth of the jar this posture was presumably assumed, to direct the sound upwards from the 'closed box' acting as a baffle. The same species while calling in open assumed a different posture to form the so-called
'Speaker Cabinet'. In this case the fore wings were raised at about 45° to the long axis and a 'Speaker Cabinet' formed by the dorsal and lateral fields of the tegmina. In order to increase the lateral walls of the Cabinet the broad femurs of the hind legs were positioned just below the lateral fields (Pl.XXVI-110). Similar 'Speaker Cabinets' have been described by Nocke (1971) and Forrest (1982) in different cricket species.
3. *Gryllus domesticus* Linné

A-Mechanism and physical nature of songs

During field observations in summer it was found that the males of *G. domesticus* call in the evening and night. As the temperature falls in July they start singing during day time as well. It is a burrowing species and its population increases considerably during monsoon months as is evident from their numbers at the light source. Mercury vapour lamps have been found to be specially more attractive about 2½ hours after sunset (Pl.XXVII-116). According to Kreasky (1972) *Gryllus* Sp. show greatest positive response to the UV (350 nm) region of the spectrum and this may be the reason for their attraction to Hg vapour lamps. The abundance of crickets during monsoon season is attributed to favourable ecological factors mainly humidity and temperature during which new generations arise and that those already living in their burrows may be driven out when rain water flushes their hidings. The males of this species keep on calling day and night provided the conditions are favourable. The singing activity reaches its peak during midnight after which it gradually declines. This is in accord with the findings of Khalifa (1950). After sunrise only few males keep calling as by this time predatory birds become active. It was found in collection made under
light source that more than 72% of the individuals were females. This is further confirmed by the observations of Cade (1979) on Gryllus integer from Texas and by those of Ulagaraj (1975) on Scapteriscus acletus Rehn and Hebard and S. vicinus Scudder in which case 83% of the crickets trapped were found to be females.

It was further observed that a day or two after a heavy shower large number of individuals were attracted to the lights but their number gradually decreased during successive days. Progressive fall in the number of individuals may be attributed to the fact that gryllids in such large number constitute great attraction for the predators to become active. Apart from this, traffic on the road causes considerable mortality. Such females which have been fertilized on the previous day may fail to join others as they may be busy laying eggs.

Structure of the stridulatory file

In the specimens of G. domesticus collected from the field and those reared in the laboratory it was found that only the file of the right tegmen (Pl.IV-12) is used during sound production. The length of the file varies from 2.58-3.01 mm (average 2.81 mm). The number
of teeth varies from 158-185 in the files (average 165 teeth, Table 4). The length of a single file is 2.88 mm and the total number of teeth is 182. The tooth density is highest (158.77 teeth/mm) at the inner, lower at the outer end (82.47 teeth/mm) and lowest (37.96 teeth/mm) near about the middle (Table 18). This overall pattern of tooth density is similar to what has been recorded in G. bimaculatus. The teeth of the left tegmina are less chitnized.

Physical nature of songs

a) Calling song: The chirps are characterized by 2-4 pulses each. The chirp duration and the inter-chirp intervals are variable. At 25°C pulses are $0.0129 \pm 0.0017$ sec long and $0.0098 \pm 0.0017$ sec apart in a 4 pulse chirp. The average length of pulses is $0.0118 \pm 0.0012$ sec and are $0.0030 \pm 0.0009$ sec apart in 3 pulse chirp at 26°C. The length of the chirp is $0.0822 \pm 0.0098$ sec and $0.0543 \pm 0.0023$ sec in 4 and 3 pulses chirps respectively. The average pulse duration is $0.0123 \pm 0.0015$ sec and they are $0.0050 \pm 0.0003$ sec apart in 3 pulse chirp at 39°C (Table 19). It seems that temperature has little effect on the pulse duration.
Table: 13

Characteristics of the stridulatory file of the male of Gryllus domesticus Linne

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Right Tegmen*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the file (mm)</td>
<td>2.38</td>
</tr>
<tr>
<td>Total teeth in file</td>
<td>182</td>
</tr>
<tr>
<td>Tooth density** (tooth/mm)</td>
<td></td>
</tr>
<tr>
<td>as per 15 teeth of file length</td>
<td>158.77</td>
</tr>
<tr>
<td></td>
<td>145.54</td>
</tr>
<tr>
<td></td>
<td>87.32</td>
</tr>
<tr>
<td></td>
<td>62.37</td>
</tr>
<tr>
<td></td>
<td>43.66</td>
</tr>
<tr>
<td></td>
<td>37.96</td>
</tr>
<tr>
<td></td>
<td>39.69</td>
</tr>
<tr>
<td></td>
<td>47.20</td>
</tr>
<tr>
<td></td>
<td>62.37</td>
</tr>
<tr>
<td></td>
<td>75.93</td>
</tr>
<tr>
<td></td>
<td>77.96</td>
</tr>
<tr>
<td></td>
<td>82.47(17)</td>
</tr>
</tbody>
</table>

* Stridulatory file of the ri, at tegmen is used.

** Tooth density listed starts with the inner end of the stridulatory file at the top of the column. The last numeral is based on 17 teeth as shown in parenthesis.
Table: 19

Pulse duration in the calling songs of *Gryllus domesticus* Linne

<table>
<thead>
<tr>
<th>Pulses</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>Temp °C</th>
<th>Average pulse duration Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 pulses</td>
<td>0.0106</td>
<td>0.0125</td>
<td>0.0138</td>
<td>-</td>
<td>35</td>
<td>0.0123</td>
</tr>
<tr>
<td></td>
<td>±0.0042</td>
<td>±0.0034</td>
<td>±0.0028</td>
<td></td>
<td></td>
<td>±0.0015</td>
</tr>
<tr>
<td>3 pulses</td>
<td>0.0116</td>
<td>0.0114</td>
<td>0.0135</td>
<td>-</td>
<td>26</td>
<td>0.0118</td>
</tr>
<tr>
<td></td>
<td>±0.0003</td>
<td>±0.0012</td>
<td>±0.0015</td>
<td></td>
<td></td>
<td>±0.0012</td>
</tr>
<tr>
<td>4 pulses</td>
<td>0.0125</td>
<td>0.0131</td>
<td>0.0131</td>
<td>0.0127</td>
<td>26</td>
<td>0.0129</td>
</tr>
<tr>
<td></td>
<td>±0.0014</td>
<td>±0.0023</td>
<td>±0.0023</td>
<td>±0.0025</td>
<td></td>
<td>±0.0017</td>
</tr>
</tbody>
</table>

+ Standard deviation

data based on 10 replicates
and the silent interval between pulses. This species produces two types of calling songs-slow and fast. Slow calling song is generally produced in the grassy fields and the males alternate the chirps. 2-3 pulses per chirp is a characteristic of this song. The average pulse duration is 0.1484 ± 0.0011 sec. The silent interval between pulses is 0.0116 ± 0.0915 sec. The length of the chirp is 0.0678 ± 0.0065 sec. (Table 20).

In calling song the chirps are produced in groups of 8-15 followed by a gap of about 0.392 sec at 26°C. The pulse rate is 16-18 pulses / sec at 26°C and 29 pulses/sec at 38°C (Text fig. 7). The regression line is $Y = -4.42 + 0.80 X$. The calculated value of 0 pulse/sec is 5.5°C. The sonograms (Pl.XI-43 and 44) show that the pulses have 4.7 kHz frequency in calling songs and 5.2 kHz (Pl.XIII-53) in alternating calling songs. During calling song the elytra are raised to about 45 degrees or more. The peak sound intensity is 82 dB at a distance of 10 cm away from the calling male.

b) Courtship song

The courtship song is composed of irregular chirps with the number of pulses varying from 2-7. Each pulse has three frequency sweeps. It is likely that the pulse is produced in three steps of scraper motion.
Table: 20

Pulse duration and silent interval between the pulses in alternation calling of *Coryllus domesticus* Linne

<table>
<thead>
<tr>
<th>I pulse</th>
<th>Silent interval</th>
<th>II pulse</th>
<th>Silent interval</th>
<th>III pulse</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
</tr>
<tr>
<td>0.0145</td>
<td>0.0164</td>
<td>0.0137</td>
<td>0.0148</td>
<td></td>
<td></td>
</tr>
<tr>
<td>±0.0009</td>
<td>±0.0011</td>
<td>±0.0014</td>
<td>±0.0011</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0106</td>
<td>0.0124</td>
<td>0.0116</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>±0.0024</td>
<td>±0.0005</td>
<td>±0.0015</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Standard deviation.

data based on 10 replicates
Effect of temperature on pulse rate in *Gryllus campestris*.
The sweeps have 5 kHz, 4.5 kHz and 3.72 kHz frequencies in a single pulse (Pl.XI-46). Initial pulse of each chirp has very low intensity with two transient components which might have been produced during both the closing and opening of the elytra. The average pulse duration of three types of pulses are 0.0058 ± 0.0007 sec., 0.0104 ± 0.0012 sec and 0.0158 ± 0.0031 sec respectively (Table 21). The central frequency of the pulses of courtship song is 4.6 kHz (Pl.XII-48 and 49).

c) **Aggressive song:**

In aggressive chirp the initial 1 or 2 small pulses of shorter duration are followed by 3-6 longer pulses but at the end there are 1 or 2 small pulses again. The chirp rate varies from 0.8-5.8/Sec and the pulse rate is 8.8-32.8/sec. The interchirp duration is about 0.0362 sec. The average pulse duration is 0.0116 ± 0.0022 sec and the silent interval between the pulses is 0.0117 ± 0.0014 sec. (Table 22). This song is stridulated when the courtship is interrupted by an intruding male or during guarding as a result a fierce fight ensues. The central frequency of the aggressive song is 4.9 kHz (Pl.XII - 50 and 51).
Table: 21

Pulse duration in the different types of pulses in the courtship song of *Cyllina domesticus* Linné

<table>
<thead>
<tr>
<th>Average pulse duration Type</th>
<th>Average pulse duration Type</th>
<th>Average pulse duration Type</th>
<th>Average of pulses of three types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td></td>
</tr>
<tr>
<td>0.0058</td>
<td>0.0104</td>
<td>0.0158</td>
<td></td>
</tr>
<tr>
<td>±0.0007</td>
<td>±0.0012</td>
<td>±0.0031</td>
<td>0.0107</td>
</tr>
</tbody>
</table>

*Standard deviation

data based on 10 replicates*
Table: 22

Pulse duration $t$ in the aggressive song of *Gryllus domesticus* Linne

<table>
<thead>
<tr>
<th>I pulse</th>
<th>II pulse</th>
<th>III pulse</th>
<th>IV pulse</th>
<th>V pulse</th>
<th>Average pulse duration $t$ in Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
</tr>
<tr>
<td>0.0109</td>
<td>0.0139</td>
<td>0.0140</td>
<td>0.0101</td>
<td>0.0089</td>
<td>0.0116</td>
</tr>
<tr>
<td>$\pm 0.0046$</td>
<td>$\pm 0.0039$</td>
<td>$\pm 0.0023$</td>
<td>$\pm 0.0054$</td>
<td>$\pm 0.0024$</td>
<td>$\pm 0.0022$</td>
</tr>
</tbody>
</table>

$\dagger$ Standard deviation
data based on 10 replicates
d) Amateur song

After the last ecdysis a young male stridulates its first trial song which may be termed as amateur song. The characteristic feature of this song, as differentiated from other songs, is a long chirp of 8-15 pulses followed by a gap of several seconds. This pattern continues for two three days then gradually moves towards the normal calling song. The function of this song is not known. The pulse duration of this song is $0.0236 \pm 0.0045$ sec. The silent interval between pulses is $0.228 \pm 0.0072$ sec. The length of the chirp is $0.4885$ sec. (Table 23). The representative sonogram (Pl.XIII-52) shows that the frequency of this song is $4.5 \text{ kHz}$.

**Mechanism of song production**

Calculations show that the number of emitted waves varies in pulses of different songs of this species. The number of sound waves emitted in a pulse of calling song is 59 as verified by Oscillograms (Pl.XXII-89). Taking 182 teeth of the representative file the percentage of teeth used is 32%. In courtship songs the three types of pulses vary in their duration but the average frequency of the song is the same in all. The respective values of $n$ are 27, 48 and 73 (Average 50, Pl.XXII-90 and 91; Pl.XXIII-92 and 93).
Table 1: Measurements of Chirp Duration for *Cryllus domesticus* Linne

<table>
<thead>
<tr>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>II</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>Xt</th>
<th>Average duration of the chirp</th>
<th>Length of the chirp</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.016</td>
<td>0.0075</td>
<td>0.0204</td>
<td>0.0306</td>
<td>0.0241</td>
<td>0.0222</td>
<td>0.0274</td>
<td>0.0233</td>
<td>0.0205</td>
<td>0.0236</td>
<td></td>
</tr>
<tr>
<td>0.0021</td>
<td>+0.0050</td>
<td>+0.0034</td>
<td>+0.0071</td>
<td>0.0037</td>
<td>+0.0043</td>
<td>+0.0021</td>
<td>+0.0017</td>
<td>+0.0031</td>
<td>+0.0045</td>
<td></td>
</tr>
<tr>
<td>0.0258</td>
<td>0.0131</td>
<td>0.0233</td>
<td>0.0170</td>
<td>0.0202</td>
<td>0.0334</td>
<td>0.0197</td>
<td>0.0145</td>
<td></td>
<td>0.0228</td>
<td></td>
</tr>
<tr>
<td>0.0033</td>
<td>+0.0057</td>
<td>+0.0022</td>
<td>+0.0045</td>
<td>+0.0024</td>
<td>+0.0032</td>
<td>+0.0031</td>
<td>+0.0051</td>
<td>+0.0051</td>
<td>+0.0072</td>
<td></td>
</tr>
</tbody>
</table>

and the silence gap between two successive chirps.
Table: 24

Calculated values of \( n \) the number of sound waves emitted by *Gryllus domesticus* Linne in pulses of different songs.

<table>
<thead>
<tr>
<th>Song</th>
<th>Average pulse duration in sec</th>
<th>Average frequency Cycles/Sec</th>
<th>( n ) x t tooth used*</th>
<th>Average percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calling</td>
<td>0.0125</td>
<td>4750</td>
<td>59</td>
<td>32%</td>
</tr>
<tr>
<td>Courtship</td>
<td>0.0058</td>
<td>4600</td>
<td>27</td>
<td>15%</td>
</tr>
<tr>
<td></td>
<td>0.0104</td>
<td>4600</td>
<td>48</td>
<td>26%</td>
</tr>
<tr>
<td></td>
<td>0.0156</td>
<td>4600</td>
<td>73</td>
<td>40%</td>
</tr>
<tr>
<td>Aggressive</td>
<td>0.0116</td>
<td>4900</td>
<td>57</td>
<td>31%</td>
</tr>
<tr>
<td>Alternation</td>
<td>0.0148</td>
<td>5200</td>
<td>77</td>
<td>42%</td>
</tr>
<tr>
<td>Amateur Song</td>
<td>0.0226</td>
<td>4500</td>
<td>106</td>
<td>58%</td>
</tr>
</tbody>
</table>

* taking 122 total teeth in the representative file.
In aggressive song the number of sound waves in a pulse is 57, in alternate calling 77 and in the amateur song 106. It may be noted that the value of \( n \) in pulses of calling and offensive songs approximate from which it can be inferred that the number of teeth used is the same. The varying frequencies suggest that the speed of the scraper varies over the file during closing motion of tegmina. In the case of courtship song while the pulse duration varies the frequency remains the same as the teeth are struck at a uniform rate. This song is a complex one as compared to the other songs of this species. The uniform frequency appears important for pair formation from a close range. In courtship song the number of teeth used is quite small as compared to the total number of the teeth present. The percentage comes to 15%, 26% and 40% which shows that this song is highly evolved as the energetic cost is considerably reduced.

The amateur song is produced by the males soon after the last ecdysis, and contains 106 sound waves in the pulse with varying amplitude which is confirmed
by a part of the pulse in the oscillogram (Pl.XXIII-94). During the production of this song it has been calculated that more than half \((0.58)\) of the file teeth are used in each pulse. As pointed out above this song gradually changes into normal calling song after 2-3 days. It may be noted that of all the species studied only this particular species produces the amateur song. Keeping in view the nature of identical pulses forming short trills it can be suggested that this is a primitive song which subsequently transforms into calling song.
B - Song related responses

Two types of calling songs are present in this species-slow and fast chirp calling songs. Both the songs are heard in the fields, though slow speed calling is common. Male to male interaction in the field starts just after sunset when two neighbouring males alternate the chirps. During day time in summer and monsoon months and at early hours of night in December G. domesticus chirps very slowly (1 chirp / 2-3 sec). When another male alternates, both chirp at half the rate than a single male stridulating alone (Pl.XIII-53). Generally a lonely male was heard singing at the alternation speed during summer days. The chirp rate becomes a little faster in alternation. Diagramatic representation based on sonogram analysis is given in Text fig.8. Similar alternation singing has been reported by Otte (1982) in Acanthogryllus. The details of synchronous singing could not be worked out.

During monsoon months, the responses between males and females of this species were studied in the field. While walking along the fields for an hour and a half hardly one or two courtship songs were heard. But mating was not observed in the field conditions. At the experimental field station observations were taken at night.
Diagrammatic illustration of A- slow calling sequence of a single male of O. domestica. B and C-alternation of chirps by two males. Modified from sonogram.
and it was found during the first quarter of July that this species comes to the light source and very often one male was found in the company of 5-7 females. The male of one group was heard producing calling song at both slow and fast chirp rate, which gradually changed into courtship song. In groups where more than one male were present occasionally aggressive chirps were also heard. Females of few such groups were brought in the laboratory. After a day or two they laid eggs which strongly suggests that a prior mating must have occurred in the field.

Both reared and field collected crickets when placed in jars in the laboratory behave almost the same way as those of Gryllus mitratus except that they are less aggressive. The other point worth mentioning is the fact that unlike G. mitratus, this species produces mixed song consisting of calling, courtship and a few aggressive chirps which overlap in the Sonogram (Pl.XIII-54). No evidence of dominance by any male was observed in the jars. When these males were placed singly in 5 jars in an area of about 3 m², no alternation song was heard.

When a female reaches a calling male's chamber the male stops calling song. Both of them flagellate their antennae and touch each other. The female becomes instantly immobile. Male starts producing courtship
song and assumes courtship posture. In some cases the male moves around the female which Pierce (1948) has termed 'dance'. The song may continue up to 20-30 sec after which the male comes closer to facilitate mounting by the female. Intermittant strokes and contacts by the antennae stimulate the adjustment of genitalia. The mounting lasts for about 17 sec after which the pair separates and stays calm for 15-20 sec becoming abnormally active again. This is evident from the manner of their hopping around, and in case an exit is provided they fall apart. Soon after separation the male is not supposed to guard as in this species the spermatophore is not consumed by the female even after 10 hours of copulation as reported by Busvine (1951). Nor is there any physical evidence on the part of the male to suggest guarding.

If the female is not receptive the male repeatedly produces the courtship song with some loud chirps and assumes the courtship posture but in the absence of any response the song may be repeated over and over again. A very common habit of both the sexes of this species is that periodically the tegmina are raised and the membranous pair of wings flicker rapidly accompanied by changing steps. A similar behaviour has been reported in Phaeophilacris spectrum Saussure by Dambach and Lichtenstein (1978).
4. Gryllodes sigillatus (Walker)

A- Mechanism and physical nature of songs

Gryllodes sigillatus (Walker) is a domestic pest and prefers starchy food. The kitchens in residential quarters are believed to be most favourable habitat for this species as not only food is abundantly available here but also ideal hidings under things infrequently disturbed. The author did not find this species in open fields either in day or night during his survey. G. sigillatus is a prolific breeder and there are several generations in a year, July and August being most favourable months for breeding. The songs can be heard throughout the year both in the day and night. Group songs can be heard at night after sunset. These songs often continue all through the night.

Structure of the stridulatory file:

In Gryllodes sigillatus both the tegmina possess a file but the right one is better developed (Pl.V-13) as it is used in sound productions. The file length varies from 1.92-2.26 mm (Average = 2.00mm). The number of teeth varies from 105-122 (Average = 116) (Table 4). A single file is 2.24 mm long bearing 117 teeth. The tooth density is 112.49 teeth/mm and 51.42
teeth/mm at the inner and outer ends respectively, while it is 44.99 teeth/mm in the middle (Table 25).

Physical nature of songs
(a) Calling song.

The calling song of *Gryllodes sigillatus* (Walker) (Pl.XIV-55) is characterized by chirps having 3 pulses each. The duration of each pulse in the individual chirp varies, the first being shortest and the third of longest duration. The chirp rate and pulse rate were found to be directly proportional to temperature, while their duration decreases with rise in temperature. The effect of temperature on pulse rate is shown in Text fig.9.

The calculated values of regression line for pulse rate are: \( \hat{Y} = -15.48 + 1.47 X \), and the value of 0 pulse/sec is 10.5°C. The three pulses are of 0.0068 ± 0.0014 sec, 0.0110 ± 0.0012 sec and 0.0167 ± 0.0010 sec respectively. The silent period between first and second pulses of the chirp is 0.0057 ± 0.0014 sec and between second and third 0.0027 ± 0.0016 sec. The chirp duration is 0.0430 ± 0.0023 sec (Table 26). The length of the chirps varies from 0.0453 sec to 0.0469 sec (Average 0.0463 ± 0.0006 sec, n = 10). The silent gap between two successive chirps varies from 0.0487 sec to 0.0563 sec (Average, 0.0512 ± 0.0022 sec) at 34°C. The calling
Table: 25

Characteristics of the stridulatory file of the male of *Gryllodes sigillatus* (Walker).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Right Tegmen*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the file (mm)</td>
<td>2.24</td>
</tr>
<tr>
<td>Total teeth in file</td>
<td>117</td>
</tr>
<tr>
<td>Tooth density** (teeth/mm)</td>
<td>112.49</td>
</tr>
<tr>
<td>as per 10 teeth of file length</td>
<td>62.22</td>
</tr>
<tr>
<td></td>
<td>52.93</td>
</tr>
<tr>
<td></td>
<td>47.36</td>
</tr>
<tr>
<td></td>
<td>44.99</td>
</tr>
<tr>
<td></td>
<td>42.85</td>
</tr>
<tr>
<td></td>
<td>44.99</td>
</tr>
<tr>
<td></td>
<td>51.42 (12)</td>
</tr>
</tbody>
</table>

* Stridulatory file of the right tegmen is used.

** Tooth density listed starts with the inner end of the stridulatory file at the top of the column. The last numeral is based on 12 teeth as shown in parentheses.
Effect of temperature on pulse rate in *Gryllodes sigillatus*
Average pulse duration is Calling song of *Gryllodes sigillatus* (Walker) at 34°C.

<table>
<thead>
<tr>
<th>Pulse I Sec</th>
<th>Silent Period Sec</th>
<th>Pulse Period Sec</th>
<th>Silent Period Sec</th>
<th>Pulse III Sec</th>
<th>Average Chirp Duration Sec</th>
<th>Average Pulse Duration Sec</th>
<th>Average Silent Period Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0068</td>
<td>±0.0014</td>
<td>0.0110</td>
<td>±0.0012</td>
<td>0.0167</td>
<td>±0.0010</td>
<td>0.0167</td>
<td>±0.0049</td>
</tr>
<tr>
<td>±0.0058</td>
<td>±0.0014</td>
<td>±0.0027</td>
<td>±0.0016</td>
<td></td>
<td></td>
<td></td>
<td>±0.0042</td>
</tr>
</tbody>
</table>

+ Standard deviation

Data based on replicates
(67)

song may continue from 4-55 min depending upon the condition of the male and a variety of other physical factors. After a break of 1-7 min on an average the male may start calling again. The frequency increases progressively from the first to the third pulse (6.1 kHz, 6.25 kHz and 6.5 kHz) of the chirp at 34°C (Pl.XIV-55). During calling the tegmina a held over the abdomen at 65 degree or more resulting in a sound of 82 dB|5 cm.

(b) Courtship song

The courtship song (Pl.XIV-56) is characterized by the chirps having 1-2 pulses each. The length of this song is 80-110 sec at a chirp rate of 4.16/sec. The average pulse duration at 27°C is 0.0128 ± 0.0036 sec (Table 27). The elytra are held at 35-40 degrees to the long exis of the body. In sonogram (Pl.XIV-57) the carrier frequency of this song is 4.425 kHz. The intensity of the song is about 50 dB at 8 cm. In the final stages the pulses become very weak and no distinct pattern is evident (Pl.XV-59).

(c) Aggressive song

This song is produced in the presence of a contesting male. At 34°C a group of chirps is produced varying from 0.6-2.5 sec depending upon the degree of aggressiveness. The aggressive song of G. sigillatus
Table: 3

Pulse duration *C. pilillatus* (male) in courtship song at 27°C

<table>
<thead>
<tr>
<th>Pulse I Sec</th>
<th>Pulse II Sec</th>
<th>Silent period between pulse Sec</th>
<th>Chirp duration Sec</th>
<th>Average pulse duration Sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0100</td>
<td>0.0125</td>
<td>0.0145</td>
<td>0.0380</td>
<td>0.0123</td>
</tr>
<tr>
<td>0.0131</td>
<td>0.0036</td>
<td>0.0092</td>
<td>0.0103</td>
<td>0.0036</td>
</tr>
</tbody>
</table>

± Standard deviation
data based on 10 replicates.
is very similar to its calling song but sonogram brings to light some differences in a few chirps (Pl.XV-60), for instance, there is variation of pulse duration at some places and sometimes 5 pulse chirps are also found. Alexander (1961) barely found any difference between these two songs. He says:

"In Gryllodes sigillatus .... the aggressive sounds are barely distinguishable from the calling rhythm......but there is no correlating reduction in aggressiveness".

In an aggressive song (Pl.XIV-58) the pulse duration and frequencies in the three pulses of the chirp are 0.0095 ± 0.0006 sec, 0.0122 ± 0.0002 sec, and 0.0152 ± 0.0014 sec (Table 28) and 6.1 kHz, 6.51 kHz and 6.65 kHz respectively. This song is produced when the tegmina are held at an angle of 65° to the abdomen. The intensity of the song is 80 dB/5 cm.

**Mechanism of song production**

Due to variation of pulses in the chirp of the calling song in *G. sigillatus* the value of \( n \) varies from the first pulse to the third (Table 29) and comes to 41, 69, 108 respectively. The average value comes to 73 (35%, 59, and 92%, average = 62%). The value of \( n \) is 57 in the pulses of the aggressive song. About 49% teeth of the file are used in the production of these pulses. In this song the variation in the pulses
### Table:  

Average pulse duration in offensive song of *G. l. nigricans* (Parker).

<table>
<thead>
<tr>
<th>I pulse</th>
<th>Silent period</th>
<th>II pulse</th>
<th>Silent period</th>
<th>III pulse</th>
<th>Chirp length</th>
<th>Average pulse duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
</tr>
<tr>
<td>0.0095</td>
<td>0.0025</td>
<td>0.015</td>
<td>0.0025</td>
<td>0.0152</td>
<td>0.027</td>
<td>0.0123</td>
</tr>
<tr>
<td>±0.0006</td>
<td>±0.0001</td>
<td>±0.0003</td>
<td>±0.0001</td>
<td>±0.001</td>
<td>±0.0003</td>
<td>±0.007</td>
</tr>
</tbody>
</table>

*Standard deviation
data based on 10 replicates.*
Table:

Calc. and val. of m. The number of sound waves emitted by different files in m. of teeth of different cons.

<table>
<thead>
<tr>
<th></th>
<th>1st pulse</th>
<th>2nd pulse</th>
<th>3rd pulse</th>
<th>Average</th>
<th>Current Average</th>
<th>Teeth</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caliber</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.0005</td>
<td>61.0</td>
<td>62.0</td>
<td>60.0</td>
<td>61.0</td>
<td>41</td>
<td>51</td>
<td></td>
</tr>
<tr>
<td>0.0125</td>
<td>61.0</td>
<td>62.0</td>
<td>60.0</td>
<td>61.0</td>
<td>66</td>
<td>52</td>
<td>62%</td>
</tr>
<tr>
<td>0.0150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.0116</td>
<td>0.0175</td>
<td>0.0175</td>
<td>0.0147</td>
<td>73</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Courtray</td>
<td>0.0120</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td>49%</td>
</tr>
<tr>
<td>0.0150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.0105</td>
<td>0.0120</td>
<td>0.0120</td>
<td>0.0120</td>
<td>73</td>
<td>67%</td>
<td></td>
</tr>
</tbody>
</table>

* Taking 10% total teeth in the representative file.
is similar to the calling song. The value of \( n \) for each pulse is 58, 80 and 101 respectively (49\%, 68\% and 86\% the average being 67\%).

It may be mentioned here that the calculated value of \( n \) as given above is not in conformity with the picture that emerges in the oscillograms (Pl.XXIII-95 to Pl.XXIV-99). These significantly different results suggest that a more complicated mechanism is involved in the calling, courtship and aggressive songs which could not be explained.
B- Song related responses

The singing schedule of *G. sigillatus* changes with temperature and humidity conditions. Soon after a leading male starts calling others in vicinity join and all begin to sing in unison (chorusing). In an enclosed space like kitchen where hundreds of crickets of both the sexes are living under various covers the sexually displaying males can attract their mates easily. That is probably the reason why there is a periodic waxing and waning in the intensity of synchrony of these songs. Apparently it seems that phonoresponse on the part of males, other than a calling male, is responsible for this group behaviour. But the experiments of Walker (1982) have lent credence to the view that certain environmental conditions trigger this response. Sometimes chorus continues for almost the whole night. Such a group of singers offer a choice for the female to select a suitable mate on his performance. Closer observations of such group singing leads the author to suggest that the chorus is a safety device also against predators particularly wall lizard which, in such a situation, is unable to concentrate on one prey and stays quiet even if it happens to be within a very close range. In the presence of a female the sexually displaying males of *G. sigillutus* exhibit 'lek'. This term as defined by Walker (1982) is
a spatial aggregation of chorusing males in the presence of a female. Such an aggregation may be resource-based which is suggestive of such sites where feeding and oviposition facilities are available. He has proposed another term 'spree' for a temporal equivalent of 'Lek' which implies concurrent display by most or all sexually receptive males whether a female is present or not.

In the habitats where this species abounds it has been observed that the younger instars of different age groups have been found in close association with the adult crickets of both the sexes under a certain cover. It could not be established with any certainty as to whether this represents a brooding behaviour or group else is a response.

If an adult male by chance happens to come in contact with another male, one of them soon withdraws without any sign of aggression. This type of behaviour is most common. Rarely it may result in one sided or mild reciprocal aggression by producing loud chirps lasting 1-2 seconds without any combat.

Under laboratory conditions when five males each were confined in ten jars it was observed that in the first two hours commotion was evident during which frequent 'touch and go' was witnessed. Within the next
12-14 hours 10-18 reciprocal aggressive (mild & intense) chirps were heard from each jar. Next day the number of such encounters was reduced to 6-10 per jar. The following day dominance of one individual was more or less established, others behaved more passively by retreating along the periphery of the jar. The dominant male was in complete control of the territory, periodically producing calling songs. Others sometimes responded by songs of lower intensity or remained silent. In the calling males spermatophores were clearly visible with a fibrous mass on the top termed as spermatophylax (Alexander and Otte, 1967) which were usually consumed as the songs terminated.

During calling if the posterior of the dominant male was touched by antennae of another male, he started producing courtship song and in eight cases out of ten in a jar the singing male was seen mounting over the adjacent passive male. In the other two cases the passive male behaved the same way with another singing male. During the production of the courtship song if the courting male is not touched again by the other male from the rear he stops producing courtship song, then turns back and sensing the presence of the other male starts singing again, flattens the body and moves backward.
This species has a high rate of cannibalism. And inspite of placing folded paper covers, cannibalism continued unabated with the result that within 6-10 days all were mutilated or eaten up leaving behind the dominant male.

In another set of experiments a singing male was provided with a mature virgin female in a jar and their behaviour was noted in all its detail. As the calling male senses her presence in the neighbourhood he moves towards her, stops calling and begins to antennate. Meanwhile a discontinuous courtship song starts with gaps ranging from 2-40 seconds. As the pair comes in contact both begin to antennate. The male keeps singing courtship song while the female remains motionless. The premounting gesture of the male includes the positioning of his posterior in front of the head of female. He then flattens his abdomen against the surface and the female begin to mount. 2-5 minutes later the pair separates. The female now carries the spermatophore which was found to be largest among all the species under investigation. It has further been observed that inspite of close guarding the female more often consumes the spermatophore.

In case the female is not receptive she moves away followed by the male in a hectic chase. If he fails to stop her he reverts to calling song.
5. *Pteronemobius fascipes* (Walker)

A- Mechanism and physical nature of songs

*Pteronemobius fascipes* prefers such habitats of high humidity as irrigated grassy fields etc., particularly during summer months. During rains it is found in large numbers everywhere in the fields. The songs of *P. fascipes* can be heard in mornings evenings and at night during summer season and predominantly from morning to noon and at night in winters. In high humidity conditions this species thrives throughout the year. During December and January when the night temperature falls below $10^\circ$C the species stops singing. During rainy season it calls throughout the day and night.

Structure of the stridulatory file

A fully developed stridulatory file of the right tegmen of this species (Pl.V-14) is used in sound production while that of the left is often found to be either poorly developed or the teeth are altogether absent. The file length varies from 0.62-0.84 mm (Average = 0.74 mm). The total number of teeth is found to be 50-68 (Average, 60) (Table 4). A single file measures 0.648 mm long with a total number of 64 teeth. The tooth density is 166.75 teeth/mm at the inner end of the file and gradually decreases to 68.67 teeth/mm towards the outer end due to progressive increase in the tooth size (Table 30).
Table: 20

Characteristics of the Stridulatory File or "wire" of 14 Common Species (Vallee)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Max. Length (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New file, tip up (I)</td>
<td>0.34</td>
</tr>
<tr>
<td>Lot 1 teeth in file</td>
<td>64</td>
</tr>
<tr>
<td>Teeth density** (teeth/cm² as per 10 teeth of file length)</td>
<td>160.95</td>
</tr>
<tr>
<td></td>
<td>144.61</td>
</tr>
<tr>
<td></td>
<td>122.65</td>
</tr>
<tr>
<td></td>
<td>106.74</td>
</tr>
<tr>
<td></td>
<td>106.30</td>
</tr>
<tr>
<td></td>
<td>73.87</td>
</tr>
<tr>
<td></td>
<td>60.67 (4)</td>
</tr>
</tbody>
</table>

* Stridulatory file of the right toon is used.

** Teeth density is calculated with the inner end of the stridulatory file at the top of the column. The last numeral is based on "teeth" as shown in parenthesis.
Physical nature of songs:

a) Calling Song:

The calling song of this species is a succession of trills each lasting 0.466-1.078 sec (Average, 0.758 sec) and are produced at the rate of 20.19-89.3 trill/min (Average, 42.07/min) at 15-35°C. The trills are produced at regular intervals (Pl.XVI-61 and 62). It has also been observed that after normal calling song male sometimes produced a short trill of 0.1 sec. Alexander (1957) in Nemobius confuses Blatchley, has reported that in some individuals during the calling song the trills are prefaced with 1-4 short pulsation detached from the rest of the trill, in others these pulses come after the trill. The observations of the present writer on P. fascipes are in accord with these findings (Pl.XVII-65).

The silent gap between trills varies from 0.34-1.59 sec (Average, 0.7035 ± 0.4248 sec) (Table 31). The average pulse duration in the calling song is 0.0071 ± 0.0021 sec. It varies from 0.0039 - 0.0094 sec at 15-35°C (Table 32), when the tegmina are cut leaving the file, scraper and a part of resonating surface intact (Text Fig.10), it was found that the frequency remains unchanged but the intensity decreases (Pl.XVII-66). The sonogram shows the carrier frequency of the calling song to be 6.106 ± 1.12 kHz. The frequency of the calling song varies
Table: 31

Different characteristics of the calling song of
stenone pulchra nigriceps (Walker)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>n</th>
<th>x</th>
<th>± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity (dB)*</td>
<td>100</td>
<td>75</td>
<td>14.143</td>
<td>16 — 78</td>
</tr>
<tr>
<td>Carrier frequency kHz</td>
<td>12</td>
<td>6.101</td>
<td>1.1</td>
<td>4.76 — 8.05</td>
</tr>
<tr>
<td>Pulse rate (pulse/sec)</td>
<td>1</td>
<td>76.04</td>
<td>9.47</td>
<td>72.13 — 110.00</td>
</tr>
<tr>
<td>Trill rate (trills/in.17)</td>
<td>1</td>
<td>42.07</td>
<td>19.77</td>
<td>20.19 — 89.3</td>
</tr>
<tr>
<td>Trill duration (length) sec</td>
<td>47</td>
<td>0.7504</td>
<td>0.2462</td>
<td>0.466 — 1.073</td>
</tr>
<tr>
<td>Inter-trill silent gap sec</td>
<td>13</td>
<td>0.7035</td>
<td>0.4248</td>
<td>0.34 — 1.59</td>
</tr>
</tbody>
</table>

Each calling song was from a different individual.
* Total no. of songs examined for this parameter at 15 — 35°C.
* Sound pressure level 1 m, 61, measured at 10°C, from the calling males.
+ Standard deviation data based on 10 replicates.
Diagrammatic representation of the ventral view of right tegmen of *pterygonotus fascipes*. Broken line represents the part from where the tegmen was cut. F. file and D. is the drum.
Table: 3

Calculated value of n = number of sound waves emitted in calling song of P. fasciger

<table>
<thead>
<tr>
<th>Average pulse duration</th>
<th>Range (SD) kHz</th>
<th>Frequency</th>
<th>Range (Hz)</th>
<th>n = Range No. of number teeth of test used</th>
<th>(Freq. pulse duration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0071</td>
<td>0.0030 - 0.0094</td>
<td>6.106</td>
<td>4.716 - 0.05</td>
<td>43.4</td>
<td>32-62</td>
</tr>
<tr>
<td>±0.0021</td>
<td>+1.12</td>
<td></td>
<td></td>
<td>+11.0</td>
<td></td>
</tr>
</tbody>
</table>

* 45 songs from different individuals were analysed at 15°C.

† Standard deviation
from 4.776-8.005 kHz at 15-35°C. The trill rate, pulse rate and the frequency are directly proportional to a temperature ranging from 10°C - 39°C (Text figs. 11,12,13). The trill duration and silent interval between trills were found to be inversely proportional to this temperature range. The duration between the start of a trill and beginning of the succeeding trill was found to be 2.77 sec at 13°C, which is reduced to 0.67 sec at 32°C. The equation of linear regression line of pulse rate comes to \( \dot{Y} = -53.19 + 5.71 X \) and the value of \( \dot{Y} \) pulse/sec comes at 9.3°C.

Courtship and Aggressive songs (b and c) - Both these songs are similar to calling song except for their trill and pulse duration which is 0.9548 sec and 0.009427 sec at 25°C respectively (Pl.XVI-63 and 64). In the court­ship song, sometimes 30-35 short pulses are also produced.

The aggressive trills (Pl.XVI-64) are not limited to courtship interference alone, but are also emitted when a rival is located within the territory when the male is calling. In such an eventuality the male stops singing the normal calling song and on reaching the intruder, assumes an alarming posture by violently
Text Fig. 11

Effect of temperature on trill rate in *Pteronemobius fasciatus.*
Text Fig. 12

Effect of temperature on pulse rate in *Pterogomphus fasciatus*. 
Effect of temperature on frequency of calling songs in *Pteronemobius fascipes*. 

Text Fig. 13
jerking its body and starts a burst of smaller trills (7-12) of 0.688 sec each. The intensity of sound increases at the close of each trill.

Mechanism of song production

As the temperature rises the pulse duration decreases resulting in the rise of frequency (table 33). The pulse duration at 15°C is 0.0080 ± 0.0004 sec and the frequency of the song is 5.08 kHz. It is 0.0039 ± 0.0006 sec and 8.216 kHz respectively at 35°C (Table 33). The number of teeth used in the pulses is the same as the wave forms in the oscillograms up to 25°-27°C, but beyond this temperature range the calculated values do not correspond with the actual wave forms present (Pl.XXIV and XXV-100-109). This discrepancy has been fully discussed under chapter VII (Discussion).

The frequency of the pulses in the song of P. fascipes like other crickets goes down and this down-slurring may be either due to the lower teeth density at the outer end of the stridulatory file or slowing down of scraper before coming to zero at the end of the pulse.
Table:

<table>
<thead>
<tr>
<th>No</th>
<th>Time (sec)</th>
<th>Juice duration (sec)</th>
<th>% of 125 sec</th>
<th>Teeth used**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.0</td>
<td>0.9</td>
<td>93</td>
<td>41</td>
</tr>
<tr>
<td>2</td>
<td>1.3</td>
<td>1.09</td>
<td>90</td>
<td>41</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>0.93</td>
<td>93</td>
<td>39</td>
</tr>
<tr>
<td>4</td>
<td>1.27</td>
<td>1.28</td>
<td>100</td>
<td>35</td>
</tr>
<tr>
<td>5</td>
<td>1.1</td>
<td>1.06</td>
<td>97</td>
<td>35</td>
</tr>
<tr>
<td>6</td>
<td>1.25</td>
<td>1.26</td>
<td>100</td>
<td>32</td>
</tr>
<tr>
<td>7</td>
<td>1.2</td>
<td>1.25</td>
<td>100</td>
<td>42</td>
</tr>
</tbody>
</table>

* Countershift Son.

** Taking OA total teeth in the representative file.
B - Song related responses

In nature where population is large, several males may call from close quarters. Trills from such males may partially or completely overlap giving an impression of singing in unison, but this could not be confirmed. If one or two males respond to a calling male by coming closer and happen to make an antennal contact the calling male assumes alarming postures. Usually the intruder retreats. In nature males have been observed producing courtship song near females though mating could not be seen under these conditions.

In the laboratory the behaviour of males in the vicinity of a calling male is akin to what has been described under field condition with the difference that the possibility of encounter increases considerably. In sequential order the interaction between males may be summarised below.

A male may approach a calling male either from behind or in front. In either case the calling male gets alerted if antennal contact is made. At this stage he may start kicking the other on the rear or may turn about and come face to face. Unilateral or reciprocal lashing of the antennal occurs. Confrontation may either result
in retreat or a combat. In the latter case, as generally happens, one of them opens the mandibles, lifts the elytra and produces aggressive trills. The other responds by assuming similar aggressive postures and stridulates. They then grapple each other and a regular combat follows during which there is a repeated engagement and disengagement ending finally in the retreat of the loser under a cover. The combat lasts for about 30-45 sec. The winner or dominant male stays in the open territory and produces calling song. If confronted by an intruder again a similar behaviour follows. Buane (1955) has reported more or less a similar behaviour of the male of Oecanthus pellucens whose dominant male confines himself in a territorial area of 50 cm$^2$.

The receptive females are attracted towards calling male. In the presence of a receptive female the male comes near and starts producing courtship trills. These are like calling trills but shorter lasting 0.9548 sec at 25°C.

These findings are in agreement with the opinion expressed by Alexander (1956) in Miogryllus verticalis (Jervilie) and Anaxipha exigua (Say). He contends that the calling song and courtship songs are similar except
the trill length which is smaller in courtship songs than in the calling. The total duration of courtship trills in P. fascipes varies from 5-8.5 min. When a calling male touches the hind of a receptive female she kicks her hind leg to keep him away. The male moves in front and produces courtship trills. Then suddenly she moves forward and mounts for a fraction of a second and dismounts. This is considered here as a trial mount because spermatophore is not yet externally visible. The male remains stationary for sometime till the spermatophore begins to protrude. The female now proceeds slowly and mounts again. This time the genitalia are adjusted with constant antennal movement. The female dismounts after receiving the spermatophore. The mating lasts for 1.5-3.5 min at 27°C. Apparently there is no guarding behaviour in this species. This behaviour is supposed to be characteristic of the genus Pteronemobius (Mays, 1971). According to him the preliminary mounting is an unique feature in Gryllidae and is a prerequisite for spermatophore production. The productive second mount leads to the coupling of the genitalia and the feeding of female on specialized tibial spurs of the male. This sequence is basically the same in 10 species of 3 subgenera studied by him.
6. **Anaxipha longipennis** (Serville)

A- Mechanism and physical nature of songs

This is a small swift moving species inhabiting top shoot of tall grasses. During survey its population was found to be limited to a small patch of tall grass in the vicinity of old deserted building in the Aligarh Fort. This species was selected for study for two reasons. Firstly, its mating behaviour is different from other species studied, secondly, its calling song was found to be of two types a) Pulsating song and b) Non-pulsating song. Since it is rarely encountered in the fields and chat too mostly at night, the field observations for that reason fall short of details. This deficiency was nevertheless compensated by rearing it in the laboratory and necessary details were worked out. Most of the experiments on this species relate to such specimens that were either reared in the laboratory or were netted in the field. During the months of August and September songs of **Anaxipha longipennis** were heard at night in the field conditions. The peak activity was recorded from 11 p.m. to 2 a.m. Sometimes the songs were also heard in day time in fields during October and November.
Structure of the stridulatory file

In *Anaxipha longipennis* the sound is produced by the file of the right tegmen which is well developed (Pl.V-15). In the left tegmen there is a file with sparcely distributed underdeveloped teeth. The file length ranges from 0.69-0.82 (X=0.74 mm). The number of teeth varies from 70-76 (X is 72; Table 4). A single file is 0.69 mm long bearing 71 teeth. The tooth density is 150.9 teeth/mm at the inner end 99.6 teeth/mm at the outer end of the file. In the middle the tooth density is 37.7 teeth/mm. (Table 34).

Physical nature of songs

a) *Calling Song*

The calling song of *A. longipennis* is characterised by regularly spaced chirps having 6-7 pulses each. The pulses are produced at 51-60 pulses/sec (Average=55 pulses/sec). The chirps last 0.0516 ± .0008 sec and are produced at the rate of about 9.16 chirps/sec at 26°C. The pulses are 0.0068 ± 0.0005 sec long. The silent interval between the pulses is 0.0021 ± 0.0006 sec (Table 35). The calling song is of two types; pulsating and non-pulsating. In the former the intensity varies from chirp to chirp and in the
Table: 3

Characteristics of the stridulatory file of the site of *Apanteles longiventris* (Fervelle)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Right Toj on*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of the file (mm)</td>
<td>0.86</td>
</tr>
<tr>
<td>Total teeth in file</td>
<td>71</td>
</tr>
<tr>
<td>Tooth density** (teeth/mm)</td>
<td>158.9</td>
</tr>
<tr>
<td>Inner 10 teeth of file length (mm)</td>
<td>93.5</td>
</tr>
<tr>
<td>Outer 10 teeth of file length (mm)</td>
<td>93.7</td>
</tr>
<tr>
<td></td>
<td>90.5</td>
</tr>
<tr>
<td></td>
<td>97.7</td>
</tr>
<tr>
<td></td>
<td>97.0</td>
</tr>
<tr>
<td></td>
<td>99.6 (11)</td>
</tr>
</tbody>
</table>

* Stridulatory file of the right tooth is used.

** Tooth density listed starts with the inner end of the stridulatory file at the top of the column. The total number is based on 11 teeth as shown in parenthesis.
Average pulse duration and average silent gap in calling song of *Anaxipha longiscema* in sec at 20°C.

<table>
<thead>
<tr>
<th>Silent Gap II</th>
<th>Silent Gap III</th>
<th>Silent Gap IV</th>
<th>Silent Gap V</th>
<th>Silent Gap VI</th>
<th>Chirp direction</th>
<th>Ave dur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
</tr>
<tr>
<td>0.0022</td>
<td>0.0069</td>
<td>0.0027</td>
<td>0.0063</td>
<td>0.0025</td>
<td>0.0064</td>
<td>0.0023</td>
</tr>
<tr>
<td>0.0065</td>
<td>+0.0003</td>
<td>+0.0007</td>
<td>+0.0003</td>
<td>+0.0003</td>
<td>+0.0002</td>
<td>+0.0005</td>
</tr>
<tr>
<td>0.0010</td>
<td>0.0067</td>
<td>0.0516</td>
<td>0.0004</td>
<td>+0.011</td>
<td>+0.0008</td>
<td>+0.008</td>
</tr>
</tbody>
</table>

Standard deviation

Based on 10 replicates
latter it is almost constant. The duration of the calling song varies from 1-3 hours. Excepting some pauses lasting 2-5 min the song otherwise is a continuous one. Sonogram indicates that the pulses have 7.45 kHz frequency (Pl.XVIII-67). During calling the elytra are held at an angle of about 70° to the abdomen and the overall peak intensity is 92 dB/3 cm. In common with the other species studied the pulse rate increases with the increase in temperature (Text Fig.14). The regression line for pulse rate was calculated to be $\hat{Y} = 4.93 + 1.97 X$, and the value for 0 pulse/second comes at $-2.5^\circ$C.

b) Courtship Song

The courtship song is composed of irregular chirps of 2-3 pulses each emitted at a rate of 18-21 pulses/sec (Average, 19.7 pulses/sec) at $26^\circ$C. The pulse duration is $0.0064 \pm 0.0002$ sec and $0.0067 \pm 0.0003$ sec in a 3 pulse chirp and 2 pulse chirp respectively. The average silent gap between the pulses is $0.0040 \pm 0.0002$ sec and $0.0032 \pm 0.0002$ sec respectively in the two types of chirps. The chirp duration in the two types of chirps is $0.0271 \pm 0.0007$ sec and $0.0160 \pm 0.006$ sec respectively (Table 36).
Text Fig. 14

Effect of temperature on pulse rate in *Anaxipha longipennis*
Table: 36

Average pulse duration, silent gap and chirp duration in the courtship song of *Anaxipha longipennis* at 26°C.

<table>
<thead>
<tr>
<th>Chirps</th>
<th>I pulse</th>
<th>Silent gap</th>
<th>II pulse</th>
<th>Silent gap</th>
<th>III pulse</th>
<th>Average pulse duration</th>
<th>Average silent gap</th>
<th>Average chirp duration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
<td>Sec</td>
</tr>
<tr>
<td>3 pulse</td>
<td>0.0064</td>
<td>0.0035</td>
<td>0.0051</td>
<td>0.0045</td>
<td>0.0077</td>
<td>0.0064</td>
<td>0.0040</td>
<td>0.0271</td>
</tr>
<tr>
<td></td>
<td>±0.0002</td>
<td>±0.0004</td>
<td>±0.0003</td>
<td>±0.0003</td>
<td>±0.0003</td>
<td>±0.0002</td>
<td>±0.0002</td>
<td>±0.0007</td>
</tr>
<tr>
<td>2 pulse</td>
<td>0.0069</td>
<td>0.0032</td>
<td>0.0065</td>
<td>0.0067</td>
<td>0.0032</td>
<td>0.0160</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>±0.0009</td>
<td>±0.0002</td>
<td>±0.0001</td>
<td>±0.0003</td>
<td>±0.0002</td>
<td>±0.0006</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Standard deviation

Data based on 10 replicates
The sonogram (Pl.XVIII-68) show the frequency of 6.95 kHz. In a typical courtship song the elytra are held at about 65 degrees and the sound intensity varies from 65-75 dB/5 cm.

C) Aggressive Song

The aggressive song is stridulated in irregular chirps having 2-7 pulses each at 26°C and are produced at a rate of 6-8 chirps/sec (Average, 7.6 chirps/sec). The pulse rate is 27-38 pulses/sec (Average 34.16 pulses/sec). The pulses are about 0.0016 sec apart. The pulse duration is 0.0051, 0.009 sec (X=0.0061) (Table 37). The last pulse is of longer duration. As is evident from sonogram (Pl.XVIII-70 and 71) the frequency varies, being higher in the middle and at the end of each chirp. It is 7.2-3 kHz. The elytra are held at about 70° to the abdomen and the overall peak intensity is 90db/4 cm.

Mechanism of song production

In calling song of *A. longipennis* the pulse duration (t) has an average value of 0.0068 sec. The value of $F \times t = 51$ which comes to 71 per cent of the total teeth of the file used (Table 38). The representative
Duration of silent period between the pulses of
nerve of Anarrhichthys ocellatus at 26°C

<table>
<thead>
<tr>
<th></th>
<th>Silent interval</th>
<th></th>
<th>Silent interval</th>
<th></th>
<th>Silent interval</th>
<th></th>
<th>Silent interval</th>
<th></th>
<th>Average pulse duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>0.0059</td>
<td></td>
<td>0.0056</td>
<td></td>
<td>0.0053</td>
<td></td>
<td>0.0051</td>
<td></td>
<td>0.0095</td>
</tr>
<tr>
<td></td>
<td>±0.0009</td>
<td></td>
<td>±0.0006</td>
<td></td>
<td>±0.0005</td>
<td></td>
<td>±0.0011</td>
<td></td>
<td>±0.0010</td>
</tr>
<tr>
<td></td>
<td>0.00017</td>
<td></td>
<td>0.0017</td>
<td></td>
<td>0.0017</td>
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<td>0.0017</td>
<td></td>
<td>0.0016</td>
</tr>
<tr>
<td></td>
<td>±0.0007</td>
<td></td>
<td>±0.0009</td>
<td></td>
<td>±0.0006</td>
<td></td>
<td>±0.0008</td>
<td></td>
<td>±0.0013</td>
</tr>
</tbody>
</table>

0 replicates
Table:  

Calculated values of the number of sound waves emitted in different pulses of songs by *Anaxiphe longipennis* (Serville).

<table>
<thead>
<tr>
<th>Song</th>
<th>Average pulse duration (Sec)</th>
<th>Average frequency (Cycles/Sec)</th>
<th>Average No. of teeth used</th>
<th>Percent teeth used*</th>
<th>Average percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calling</td>
<td>0.0000</td>
<td>7450</td>
<td>51</td>
<td>71%</td>
<td>71%</td>
</tr>
<tr>
<td>Courtship in 3 pulse chirp</td>
<td>0.0040</td>
<td>6250</td>
<td>26</td>
<td>39%</td>
<td>35%</td>
</tr>
<tr>
<td>in 2 pulse chirp</td>
<td>0.0030</td>
<td>6250</td>
<td>22</td>
<td>31%</td>
<td>31%</td>
</tr>
<tr>
<td>Aggressive</td>
<td>0.0160</td>
<td>7200-2000</td>
<td>44-49</td>
<td>62%-69%</td>
<td>65%</td>
</tr>
</tbody>
</table>

* taking 71 total teeth in the representative file.
file has a total of 71 teeth. The calculated value of n is 28 and 22 respectively (39.5% and 31% of the file teeth) in pulses of 2 types of chirps of courtship song. The calculated value of n is 44.49 (62%-69%). As the pulse duration is the same for pulses of different frequencies, the speed of scraper over the file is in faster in pulses of higher frequency than those of the lower.
B- Song related responses

In nature if two calling males approach each other one of them starts producing aggressive song lasting 20-40 sec the other then usually withdraws without any sign of aggression. In response the former resorts to normal calling.

Under laboratory conditions when males (n=5) were confined in jars usually one was heard producing calling song mostly at night from some suitable site. If another male ventures to make antennal contact the calling song stops and aggressive chirps are produced to keep the other at bay. In case two males happen to call simultaneously from a single jar no temporal interactions between chirps of their calling song were discernable.

Both receptive and non-receptive females of this species respond favourably to the calling song of the male. On sensing the presence of a female the male comes closer and the antennal tips of both meet keeping their bodies apart facing each other. Laboratory observations on several pairs (n=12) suggest that all courtship and mating activities occur on the vertical wall of the glass chamber and never at its bottom. The mating
sequence is as follows: The female approaches the singing male and stations itself on the vertical glass wall with her head facing downwards. She stays motionless. Meanwhile the male starts the courtship song and wavers the body facing the female. The singing male then turns about and lines himself up in such a way that the abdomen points towards the head of the female at a distance of 1.00 - 2.5 cm from the female head. Some pairs were found aligning themselves obliquely in a similar manner. The courtship songs may last from 15 sec to 2.5 min. The singing male now closes the elytra and immediately darts back to lie beneath the female, attaches his spermatophore to the right side of the genitalia and dashes out. A similar type of copulatory behaviour has been observed by Walker (quoted by Spooner, 1973) in Crytoxipha columbiana Caudell. The entire operation in A. longipennis is so quick that it hardly takes 1.0 - 1.5 sec and is repeated 4-7 times in case the spermatophore is eaten by the female. The manner in which the spermatophore is picked up is also different from others. Instead of turning abdomen headwards as in other species, the female moves the right hindleg backward to scratch out the spermatophore with the claws and eats up. After every mating the male guards for a while (1-2 min), finally parts company with the female.
VII. DISCUSSION

Mechanism of sound production

It is a matter of common observation that all gryllids are provided with one set of almost equally developed sound producing structures in each tegmen. There is a stridulatory file which is a modified lower cubital vein and a scraper formed by the antero-internal edge of the tegmen. The file consists of a series of downwardly projecting teeth. This structure is present only in the males. Normally in all the six species studied the right tegmen overlaps the left so the file of the right tegmen and the scraper of the left is used in sound production. For experimental purposes when the left tegmen was put over the right in anaesthetised males they were observed assuming their normal position after regaining consciousness. The time factor however, in different species varies. Observations on *G. bimaculatus* are in accord with those of Stärk (1958) where the position is reported to be reversed within a few minutes.

In case of *P. fascipes* individuals habitually change wing position but singing occurs only while the wings are in R/L position. Spooner (1973) has reported an exceptional case of a katydid specise (*Cyphoderris monstrosa*) from United States whose males switch over wing position regularly during calling.
Most commonly in nature sound is produced when the right tegmen is over the left. The other set has been regarded here as a spare one which can be used under emergency conditions. The experiment of Rakshpal (1960) can be advanced in support of this view in which case the file and its corresponding scraper in normal use were mechanically destroyed in *Acheta veletis* leading to spontaneous change to L/R position and the sound production became possible again. On the other hand Stärk (1958) has reported that in *G. bimaculatus* if the position of the tegmina is changed in the fourth instar nymph it retains this inverted position and stridulates. When the position of the tegmina is again reversed when the insect begins to stridulate it reverts to the position (L/R) in which the wings were put at nymphal stage. This is suggestive of a certain tendency akin to left handedness in man.

In natural population of *Acheta assimilis* and *A. pennsylvanicus* it has been shown that about 4-10% individual are left winged (Rakshpal, 1960). In *Gryllootalpa gryllotalpa* and *Acheta domesticus* (Golda and Ludwig, 1958) it was reported that the proportion of the individuals with naturally occurring inverted tegmina is very small 1/2000. Further it has been reported that
the songs of $L/R$ insects are generally weaker in intensity in *G. campestris* (Keilbach, 1935) than those of normal ones.

It has been experimentally proved that the structures associated with sound production are generally controlled by a polygenic system (Dumortier, 1963). The occurrence of a very small fraction of male population having $L/R$ tegminal position may be controlled by some rare recessive gene. This can also be explained in terms of selection. The songs of $L/R$ individuals are weaker (Keilbach, 1935) and are less likely to attract a mate consequently fewer such males in the population. The reverse position is positively in favour of selection whence larger number of $R/L$ insects in the population.

The length of the file and the number of teeth vary in different species studied. Both these parameters are species-specific. Of the six gryllid species studied there does not seem to be any correlation between the file length, number of teeth and tooth density. For instance, in *P. fascipes* the number of teeth is lowest (50) in 0.62 mm long file while highest number (383) is found in *G. mitratus* with a shorter
file than that of G. bimaculatus (Table 4). Likewise, there is no relationship between the length of the file and the tooth density in the species under consideration. The highest tooth density is 158.77 teeth/mm in G. domesticus and the lowest 30.39 teeth/mm in G. mitratus (Tables 18, 5). In some cases as in G. mitratus and P. fascipes, the tooth density is highest at the inner end and decreases at the outer lateral end of the file where it is lowest. Similar condition has been reported by Spooner (1973) in Cyphoderris monstrosa. In the other four species studied the tooth density is highest at the inner end and lowest somewhere near the middle, rising again at the outer lateral end of the file.

The tooth density, the number of teeth and the length of the file are species-specific and provide good diagnostic characters for species identification. Alexander and Thomas (1959) prepared a key of Nemobius fasciatus group by using number of teeth as a reference parameter. Similarly Walker (1973) has prepared another key of United States and Caribbean Anurogryllus taking all the three parameters along with some morphological and song characteristics into consideration. Walker and Carlyle (1975) have suggested that it may be possible to identify most of the crickets up to subfamily
level on the basis of file tooth structure. Apart from these, other features of the elytra like tooth density, mirror and harp are also important diagnostic features in crickets.

Regarding the mechanism of sound production, the gryllids present a simpler mechanism as compared to tettigoniids. The experiments of Pierce (1948) and of Walker (1962b) are particularly enlightening. Pierce (1948) with the help of cinematography established that in gryllids the sound is produced during closing movement of the tegmina. He arrived at this conclusion by observing that for a series of three pulses the wing closing motions were evenly spaced. Since the three pulses of sound were also similarly spaced he concluded that the sound is produced during closing motion of the wings. Walker (1962b) presumed that closing and opening of the wings constitute one complete cycle and discovered that the rate of complete cycles is equal to the pulse rate. From this he further concluded that since the rate of the two is the same and not different as would be expected if both closing and opening movements of the elytra were acoustically effective. Therefore only one movement is responsible for sound production and that could be only during the closing movement. That the sound, according to him, is produced by this stroke only is further supported by an indirect evidence from
the structure of the file in which the teeth are mesally directed.

Structural studies of the files of the six species under study fully confirm this point of view. But the categorical statement of Walker (1962b) that the sound is produced only during the closing movement of the elytra implying thereby that no sound is produced during opening movement is not entirely immune to criticism. If tooth drop implies file scraper contact causing the membrane to vibrate at the tooth impact rate then it is bound to happen during both closing and opening movements. When the scraper moves against the mesally directed teeth the sound is louder and that in the reverse direction (opening) sound should be produced but may be of a very low intensity. Sound however, will not be produced if the left elytron is slightly lowered during opening so that the scraper does not touch the teeth at all. This is quite likely as the up and down movement of the tegmina is possible. But in case it comes in contact with some teeth sound has to be produced whatever be its quality. Alexander (1957) says:

"However, when brief contact of the file and scraper occurs on the 'backstoke' (probably the opening of the tegmina), a slight rise in frequency occurs, indicating that file-tooth spacing is probably the important factor".
In some sonograms of various songs of gryllids at temperatures above 25°C there is no silent gap between two adjacent pulses in the chirp, instead they are connected together by distinct sound signals (Pl.VIII-30 and 31; Pl.X-40; Pl.XII-51; Pl.XVI-62 and 63; Pl.XVIII-70 and 71). These signals when analysed on the storage-scope reveal that between the two successive trains of elementary waveform, corresponding to two closing motions of the tegmina, there are yet other waves which are continuous with the preceding and succeeding waveform envelopes (Pl.XXII-87; Pl.XXIII-92; Pl.XXIV-103; Pl.XXV-104 and 105). Such a picture is regarded here as having been caused by the opening motion of the tegmina for otherwise there should necessarily have been a silent gap between. Another interesting fact is that this phenomenon is directly related to temperature. At temperatures below 25°C only the closing motion of tegmina was found to be acoustically effective but above this temperature both the wing motions produce sound signals—a fact which is confirmed by storage-scope. At 19°C there is a silent interpulse gap in the sonogram (Pl.XVI-61). When this is analysed in the storage-scope an interpulse connection is seen which has been regarded here as due to dying amplitude of sound waves from the resonating surfaces of the tegmina (Pl.XXIV-101).
The above discussion on the basis of present experiments conducted can be summarized as follows:

1. The tooth impact rate determines the carrier frequency of the song.
2. Different songs have different frequencies.
3. At higher temperature range 25°C-35°C the 'back stroke' (opening motion of tegmina) is also acoustically effective.
4. The song frequency is also the frequency of the tegmina as a whole or a part thereof and that
5. The frequency is generated by the tooth impact rate.

From the observations on different songs of various species it may reasonably be concluded that the natural frequency of the tegmina is variable and that it can be tuned according to the frequency of the song, implying thereby that there is a distinctive range of tegminal natural frequency. Further, it has been noticed that cutting of certain parts of the tegmina does not affect the frequency but only reduces the intensity of the song. It will be pertinent to quote here some important workers. Sismondo (1979) marked certain areas of the tegmen for specific songs of the Oecanthus which resonate according to the pulse frequency at the tooth-impact rate. Besides there is a series of tegminal resonance (from 5.1 kHz - 5.8 kHz) outside the tooth-impact frequency. After
comparing these data with those of *Gryllus* he supported the concept of a resonator with continually variable tuning. 'Nocke (1971) has advanced the idea of 'harp' as a resonator of the elytra which delivers the frequency with an added amplitude. Dumortier (1963) proposed two alternative mechanisms to account for acoustic performance of the cricket at variable tooth impact frequency. a. The tegmina posses a continuous series of natural frequencies each of which may be excited in resonance with the prevailing tooth-impact rate frequency or b. The tegmina are passive surfaces which move perpendicularly to their planes when actuated by the file and scraper mechanism, at whatever frequency the latter generates, and without involving their own natural resonances. The conclusions of the present author are in accord with the first proposition of Dumortier.

An interesting feature of the calling song is that the frequency within a pulse shows a distinct down-slurring at the end of the pulse in all species except *Anaxipha longipennis* where it is not so conspicuous. Several plausible explanations may be advanced to explain this phenomenon. In the opinion of the present author the fact that the speed of the scraper progressively decelerates as it reaches the lateral end of the file before
it actually stops to zero seems to contribute more
in the downslurring process. Another explanation
could be the one suggested by Alexander (1957) that
the file teeth are less dense at the lateral end of the
file. The carrier frequency therefore decreases towards
that end. In such gryllids where the teeth are dense
towards the lateral end of the file some teeth according
to Walker (1962b) are not used in sound production.
This idea has been further elaborated by Spooner (1973)
to suggest that the carrier frequency is bound to fall
if the scraper does not touch the dense teeth at this
end. May be, this factor either alone or in combination
with the one given above may be responsible for the
downslurring of the frequency in each pulse.

The pulse in the aggressive songs of G. mitratus
and courtship song of G. domesticus also show downslurring
but not as smooth or gradual as in the calling song.
It seems to occur in 2-3 steps with three to four
different frequency steps, the frequency decreasing in
every successive step. The tooth density of the file
may explain a gradual downslurring but not a stepwise
erratic change in the carrier frequency. It appears more
probable that the scraper during the closing motion of
the tegmina moves with varying speed slowing down at the close of each step resulting in a 3-4 distinct frequency bands.

The basic unit of a song pattern is the pulse which is repeated in different order in each song. The frequency, repetition of pulse groups (chirp/trill) forming the temporal sequence and the intensity make the songs species-specific. Sonograms reveal that number of pulses per chirp in the calling songs vary in all species under study except in *Gryllodes sigillatus* where 3 pulses per chirp have been recorded. In the same species Alexander (1960) has reported the existence of 4 pulses per chirp. Popov (1972) has reported 3-5 pulses in each chirp of the calling song in *Gryllus bimaculatus* while it was found to be 3-4 pulses in the present study.

It has already been mentioned earlier that the species-specific calling, courtship and aggressive songs differ in both quality and quantity among individuals belonging to different species. In the trilling species *Pteronemobius fascipes* these differences are minimal. In other trilling species viz *Nemobius fasciatus* the trills in the courtship song become shorter than in calling songs, while in *Anaxipha exigua* the continuous trill of calling song is modified into short trills (Alexander, 1956).
Minor differences in the sound producing structure in four different genera notwithstanding, an attempt at comparison between different songs may be found to be instructive. The precourtship song of Gryllodes sigillatus is characterized by irregularly produced chirps consisting of two pulses each which in full courtship changes into irregular very short pulses of wide frequency. More or less similar thing happens in Gryllus bimaculatus. In case of G. mitratus chirp + trill are produced in precourtship song which is similar to calling song of Teleogryllus commodus (Rence and Loher, 1978). In full courtship song however, the chirp portion is deleted. In G. domesticus the frequency widens with an increase in the number of pulses/chirp. At the tail end of its full courtship song some middle frequencies are knocked out from the wide frequency sweep leaving upper and lower frequencies intact as seen in sonograms.

Alexander and Thomas (1959) have stated that in Gryllinae a distinctive more or less continuous rhythm is produced during the final stages of courtship and this is so similar in Acheta, Gryllus and Gryllodes sigillatus that a common origin of the above has been suggested. This contention holds true in Gryllodes sigillatus and Gryllus bimaculatus but is not in conformity with the observations made on G. mitratus and G. domesticus.
The number of pulses increase in the aggressive songs of chirping species studied and the frequency sweep widens except in *Gryllodes sigillatus* where some chirps of 4 pulses appeared in sonogram. Alexander (1962) discusses the origin of the aggressive sounds from calling songs by adducing several facts in support of such a contention. He holds the view that though the two signals differ structurally in a quantitative fashion yet some of the aggressive chirps are exactly like the calling chirps. Sonogram of the aggressive song of *G. bimacutus* (cf. Pl.X-38) supports this view.

**Interaction among sexes**

It has been observed that encounters between two adult male crickets usually terminate in the withdrawal of one and dominance of the other. The retreat is affected under three situations as given below, of which one of the alternatives may be preferred.

1. Accidental antennal contact either from behind or from front without exhibiting any sign of aggressiveness. One of the males may retreat quietly.
2. Between the time of initial contact and the eventual retreat, both the contenders exhibit mild or intense aggressive postures by lashing the antennae, rocking the bodies accompanied sometimes by aggressive chirps. At one stage one of the male decides to retreat.

3. Initial reciprocal advance by matching males followed by severe combat after which one retreats. This behaviour is invariably triggered when an intruder disturbs a guarding male.

Alexander (1961) has given a comprehensive account of interaction between two adult male of North American cricket species of the genus *Acheta* and the kind of aggression exhibited has been categorized under the following 5 levels:

"First level - contacts terminated without clear dominance, no apparent retreat, and no apparent aggression.

Second Level - contacts terminated by retreat without apparent aggression.

Third Level - contacts terminated by retreat after mild to moderate one-sided aggression or mild reciprocal aggression."
Fourth Level - contacts terminated after moderate to intense reciprocal aggression.

Fifth Level - contacts terminated only after sustained combat".

A comparision of these levels with the observations made on the crickets under study it appears reasonable to suggest that the first level of the present study conforms broadly to the first and second levels of Alexander (1961) and that his third and fourth levels can be merged into one as the second alternative in the present study. The fifth level of Alexander corresponds precisely to the third alternative.

From the above observations it is also evident that in Gryllus species the aggressive behaviour is territory-oriented except in G. domesticus which is least aggressive inspite of its burrowing habits. Alexander (1961) pointed out that in case of those species which burrow rarely there is much less aggression than in those which habitually live in burrows. Loher and Renee (1978) maintain that aggressive behaviour is a species-specific signal which helps in maintaining distance among males and monopolizing the female during guarding.

When large number of these species aggregate near the light source with females out-numbering the males their aggressiveness is surprizingly reduced. This-
is perhaps due to the stress caused by the loss of their own territory and the presence of large number of females around. Crowding under laboratory conditions results initially in the interaction of the 'first level' but with the passage of time some individuals begin to show signs of aggressiveness yet no actual combat occurs. It was noted that prolonged contact establishes dominance of one male in all the species except *Gryllus domesticus* and *Anaxipha longipennis*. Longer association among such males often leads to courtship even in the absence of females.

In the present study *Gryllus mitratus* and *G. domesticus* exhibit interaction between rhythms. These species have a variable chirp rate at any given temperature while in other species which have a more or less definite and fixed chirp rate at a particular temperature no such interaction was in evidence. It is interesting to note that in these two species inspite of variable chirp rate the females are drawn towards the males which is suggestive of the fact that the chirp rate is necessarily not a species recognition parameter of the song. As to why such alternating songs are heard in the fields at day time in summer and at early night in winter is not clearly understood. The temperature
and light intensity either alone or together may trigger off such a slow song.

Alteration by two individuals may have some advantages also, for instance, it helps maintaining inter-male distance in the field and that since a lesser amount of energy is expended during alternate singing the song can be sustained over longer period of time. It also acts as a safety device against predators. In Acanthogryllus fortipes, Cade and Otte (1982) have demonstrated alteration of song. In this case the chirp rate of alternating male slows down to 30-60% of the non-alternating males while in the two species studied the chirp rate is around 50%.

The singing in chorus of a few calling males of G. sigillatus and G. domesticus is a feature commonly observed both in the laboratory and field conditions at night. Few calling males (1-3) particularly of G. sigillatus may sing out of chorus. These callings are also resource-based that is, the aggregation of males occurs where conditions are most favourable for the survival of the colony and that sufficient number of females are available for prospective mating. Chorus enhances the sound output and lures more females. According to Alexander (1975) group singing provides
opportunity to the females for selecting suitable mate. In such an aggregation the males can attract a larger number of females which may not be possible if the males sing alone. Walker (1964) has suggested that the group singing prevents the predator to concentrate on one male as they stop singing at a slightest disturbance. When one stops, other singing males distract the predator from the silent one.

It appears that alternation, chorus and aggressive songs have evolved as a functional necessity to adjust the spatial requirements within hearing range. At places where several males are at a distance but still within the hearing range they resort to alternation (Gryllus mitratus and G. domesticus) but if the space is narrowed down to visual and tactile level aggression starts. Midway between these two extremes chorus or partial overlapping of chirps is resorted to as in Gryllodes sigillatus, Gryllus domesticus and G. mitratus.

Mating behaviour between sexes can be divided into 3 stages:

a) preliminaries performed by male in the production of courtship song leading to progressive change of various signals;
b) mounting by the female over the male occurs in all species except *A. longipennis* in which case the female remains stationary and the male swiftly moves under the female to attach its spermatophore;

c) Post-copulation: behaviour includes guarding of the female till the spermatophore is emptied.

Most of the crickets studied start calling after sunset except *Gryllodes sigillatus* and *Pteronemobius fascipes* which have no distinctive dial pattern. The calling activity starts declining and it ends at dawn. This is probably due to the availability of a larger number of responsive females during early hours of night and subsequently declines to end at dawn. According to Walker (1982) a major reason for the strictly nocturnal acoustic activity of the crickets is the presence of sharp-eyed diurnal predators as has been observed in case of *Oecanthus fultani* which lives in relatively open places, while a closely related species *O. nigricornis* lives in safer herbaceous vegetation and therefore calls and mates during day as well as at night. The two species in the present study (*Gryllodes sigillatus* and *Pteronemobius fascipes*) which live in partially protected environment behave in a similar way. Walker (1982) also
noted that if a predator is active for a shorter duration at night the crickets may postpone their activity and shift to some other time. On the other hand if the predator is effective throughout the night with a low capture rate then females move out together. *Gryllodes sigillatus* behaves in a similar way in the presence of the house lizard which is active throughout the night.

In the present studies almost all the *Gryllus* and non *Gryllus* species have been found singing from places higher up during the monsoon months since their terrestrial hideouts get flooded. With the approaching winters the night temperature falls and their nighttime calling is curtailed. This loss is compensated by resorting to calling in the warmer mornings and afternoons. Similar observations have been reported by Nielsen and Dreisig (1970), and Walker (1982). Daytime songsters usually select a thorny bush if available nearby dense vegetation to avoid being maimed by keen-eyed predators like birds. Temperature, predation and rainfall are perhaps important ecological factors responsible for such a behaviour of the crickets in Indian tropics. It appears that the stridulatory activity of crickets is largely dependent on the physiological state of the individual and that external factors of
ecology can have a modifying effect on their singing schedule.

Male crickets produce calling song to attract the females. For the sound signal to be more effective at longer distances cricket species of similar habits according to Forrest (1982) use similar baffle system. Ground dwelling forms according to him use body parts to increase the efficiency of sound produced. Burrowing forms use subsurface homes as sound guide and acoustic amplifier as the horn shaped burrows of Gryllotalpa vinacea and G. gryllotalpa (Bennet-Clark, 1970). Nickersor et al. (1979) studied the burrows of mole crickets and found them to be acoustically efficient. Gryllids inhabiting vegetation use leaves as baffle.

The resonating membranes of the tegmina (dipole radiator) are very small as compared to the wavelength of the sound produced. When these membranes vibrate two waves are produced in opposite phases so that the outputs cancel each other along the edges of the vibrating membrane. In order to minimize this destructive interference male crickets employ various body structures and assume various body postures according to the requirement of the situation. Experiments conducted on
\textit{gryllus bimaculatus} show that the same individual can adopt different postures in different situations to maximize the efficiency of the sound produced. It appears that there is some feedback mechanism by which the cricket can assess the efficiency of the sound and has the capability to adjust to changed situation. Jar experiments further show that the tegmina of \textit{G. bimaculatus} are held parallel to the bottom at a distance which is approximately $1/4 \lambda$. This position according to Forrest (1982) is ideal for the efficiency of sound. He says,

"If a cabinet is closed such that the distance from the disc to the cabinet's back wall is one quarter of a wavelength of the sound produced, the cabinet ("a closed box") will act as a resonating chamber. The acoustical energy of the one output is used as mechanical energy to help drive the oscillator".
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PLATE - 1

Fig. 1. Photograph of Kay Sonograph, 7629A.

Fig. 2. Photograph of Stereoscope, 45 - B123.

Fig. 3. Photograph of Sound Level meter, 2225.
PLATE - II

Fig. 4. Photograph of a pair of *Gryllus mitratus*

Fig. 5. Photograph of a pair of *Gryllus bimaculatus*.

Fig. 6. Photograph of a pair of *Gryllus domesticus*. 
Fig. 7. Photograph of a pair of *Gryllodes sigillatus*.

Fig. 8. Photograph of a pair of *Pteronomobius fascipes*.

Fig. 9. Photograph of a pair of *Anaxipha longipennis*.
PLATE - IV

Fig. 10. Microphotograph of a stridulatory file of the right tegmen of Gryllus nitrat us at 25x.  
Note the tooth density in the file.

Fig. 11. Microphotograph of a stridulatory file of the right tegmen of Gryllus binaculatus at 21x.

Fig. 12. Microphotograph of a stridulatory file of right tegmen of Gryllus domesticus at 21X.
Fig. 13. Microphotograph of a stridulatory file of right tegmen of *Gryllodes sigillatus*. 40x.

Fig. 14. Microphotograph of a stridulatory file of right tegmen of *Pteronemobius friscipes* at 175x.

Fig. 15. Microphotograph of a stridulatory file of right tegmen of *Anaxipha longipennis* at 145x.
Fig. 21. Sonogram of the slow calling song of *Cryllus mitratus* in the field conditions at 25°C.

Fig. 22. Sonogram of the slow calling song of *Cryllus mitratus* in the field at 25°C.

Fig. 23. Sonogram of the alternation calling song of *Cryllus mitratus* in the field at 25°C.

Fig. 24. Sonogram of the group courtship song of *C. mitratus* at 30°C.

Fig. 25. Sonogram of the aggressive chirps during fighting of *C. mitratus* at 30°C.
Fig. 26. Sonogram of the slow calling song of *Gryllus mitratus* at 30°C.

Fig. 27. Sonogram of the calling song of *G. mitratus* at 30°C.

Fig. 28. Sonogram of the calling song of *G. mitratus* at 32°C.

Fig. 29. Sonogram of the calling song of *G. mitratus* at 35°C.

Fig. 30. Sonogram of the calling song of *G. mitratus* at 38°C.

Note the sound signals at some places in the interpulse gap.

Fig. 31. Sonogram of the calling song of *G. mitratus* at 39°C.

Fig. 32. Sonogram of the calling song of *G. mitratus* at 30°C.

Note the partial overlapping of chirps by two males.
PLATE VIII

CALLING 36°C 26

CALLING 36°C 27

CALLING 32°C 28

CALLING 35°C 29

CALLING 38°C 30

CALLING 39°C 31

CALLING INTERACTION 32
PLATE - IX

Fig. 33. Sonogram of the 3 pulse calling song of *Gryllus bimaculatus* at 30°C.

Fig. 34. Sonogram of the 4 pulse calling song of *Gryllus bimaculatus* at 30°C.

Fig. 35. Sonogram of the pre-courtship (primary) song of *G. bimaculatus* at 30°C.

Fig. 36. Sonogram of the pre-courtship (primary) song of *G. bimaculatus* at 30°C.

Fig. 37. Sonogram of the secondary courtship song of *G. bimaculatus* at 30°C.
PLATE IX

CALLING 33

CALLING 34

PRE-COURTSHIP 35

PRE-COURTSHIP 36

COURTSHIP 37
Fig. 38. Sonogram of the aggressive song of *Gryllus bimaculatus* at 30° C.
The first chirp is similar to calling song.

Fig. 39. Sonogram of the calling song of *Gryllus bimaculatus* when the terminal membranes are experimentally out. at 30° C.
Note the additional frequencies generated.
The carrier frequency remains the same.

Fig. 40. Sonogram of the calling song of *G. bimaculatus* showing sound between inter-pulse gap at 37° C.

Fig. 41. Sonogram of the calling song of *G. bimaculatus* showing harmonics. at 30° C.
PLATE - XI

Fig. 42. Sonogram of the slow calling song of *Gryllus domesticus* at 30°C.

Fig. 43. Sonogram of the calling song of *Gryllus domesticus* with gaps after some chirps at 26°C.

Fig. 44. Sonogram of the calling song of *Gryllus domesticus* at 26°C.

Fig. 45. Sonogram of the pre-courtship song of *Gryllus domesticus*.

Fig. 46. Sonogram of the courtship song of *Gryllus domesticus*.
PLATE - XII

Fig. 47, 48 and 49. Sonograms showing difference in the courtship songs of G. domesticus.

Fig. 50 and 51. Sonograms showing the aggressive songs of G. domesticus.

Both the strokes of the tegmina are acoustically effective.
Fig. 52. Sonogram of the auditory song of *Gryllus domesticus*.

Fig. 53. Sonogram of the alternation calling song of *G. domesticus* under field conditions.

Fig. 54. Sonogram of the fixed songs by a group of *G. domesticus* males under laboratory conditions.
PLATE XIII

A M A T E U R  

A L T E R N A T I O N  

G R O U P  

FREQUENCY IN KHZ

TIME IN SECONDS

0.0  0.2  0.4  0.6  0.8  1.0  1.2  1.4  1.6  1.8  2.0  2.2  2.4  2.6
PLATE - XIV

Fig. 55. Sonogram of the calling song of Gryllodes sigillatus at 34°C.

Fig. 56. Sonogram of the pre-courtship song of G. sigillatus at 27°C.

Fig. 57. Sonogram of the courtship song of G. sigillatus at 27°C.

Fig. 58. Sonogram of the aggressive song of G. sigillatus at 34°C.
PLATE XIV

CALLING

PRE-COURTSHIP

COURTSHIP

AGGRESSIVE

TIME IN SECONDS
PLATE - XV

Fig. 50. Sonagram of the final stage of courtship song of Gryllodes sicillatus

Fig. 60. Sonagram of the aggressive song of G. sicillatus. Note that some chirps contain 3 pulses.
PLATE XV

COURTSHIP

AGGRESSIVE
Fig. 61. Sonogram of the calling song of *Pteronemobius fascipes* at 10°C.

Fig. 62. Sonogram of the calling song of *P. fascipes* at 25°C.

Fig. 63. Sonogram of the courtship song of *P. fascipes* at 25°C.

Note the closing and opening strokes of tegmina are acoustically effective as in the sonogram above.

Fig. 64. Sonogram of the aggressive song of *P. fascipes* at 25°C.
Fig. 65. Sonogram of the calling song of *Pteronobius fascipes* showing a group of pulses preceding the trill at "o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-o-}

Fig. 66. Sonogram of call: song of *Pteronobius fascipes* at 15°C after experimentally cutting the resonating parts.
PLATE XVII

CALLING 65

CALLING 66
Fig. 67. Sonograms of the calling song of *Anaxipha longipennis* at 26°C.

Fig. 68 and 69. Sonograms of the courtship songs of *Anaxipha longipennis* at 26°C.

Fig. 70 and 71. Sonograms of the aggressive songs of *Anaxipha longipennis* at 26°C.

Note that there is no interpulse gaps between pulses.
Fig. 72. Oscillogram of two pulses of calling song of *Cryllus nitrat*us at 30°C. Time: 5 m sec/division
(The envelope of the second pulse is incomplete)

Fig. 73. Oscillogram of two parts of a single pulse joined together. Calling song of *C. nitrat*us at 30°C. Time 2 m sec/div.

Fig. 74. Oscillogram of clicks of courtship song of *C. nitrat*us at 30°C. Time: 2 m sec/div.
Fig. 75. Oscillogram of a single pulse of chirp portion of courtship song of *G. miteratus* at 30°C. Time: 2 m sec/div.

Fig. 76. Oscillogram of a pulse of courtship song of *G. miteratus* at 30°C. Time: 2 m sec/div. Note the interpulse mild signals.

Fig. 77. Oscillogram showing pulses of trill part of courtship song of *G. miteratus* at 30°C. Time: 2 m sec/div. Note the continuity of sound signals.

Fig. 78. Oscillogram showing a pulse of aggressive song of *G. miteratus* at 30°C. Time: 2 m sec/div. This pulse is produced by complex wing motion.

Fig. 79. Oscillogram showing a pulse of a normal aggressive song of *G. miteratus* at 30°C. Time: 2 m sec/div.
Fig. 80. A two step pulse of aggressive song of *G. mitratus* at 30°C. Time: 2 m sec/div.

Fig. 81. A pulse envelope of 3 pulse calling song of *Gryllus bimaculatus* at 30°C. Time: 2 m sec/div.

Fig. 82. A pulse envelope of 4 pulse calling song of *G. bimaculatus* at 30°C. Time: 2 m sec/div.

Fig. 83. Oscillogram of a pulse of primary courtship song of *G. bimaculatus* at 30°C. Time: 2 m sec/div.

Fig. 84. Oscillogram of another pulse of primary courtship song of *G. bimaculatus* at 30°C. Time: 2 m sec/div.

Fig. 85. Oscillogram showing short irregular pulses of secondary courtship song of *G. bimaculatus* at 30°C. Time: 2 m sec/div.
Fig. 86. Oscillogram of a portion of pulse of aggressive song of *Cryllus bimaculatus* at 30°C. Time: 2 m sec/div.

Fig. 87. Oscillogram of a pulse of calling song of *C. bimaculatus* at 30°C, showing sound waves in the inter-pulse gap during the opening motion of the tegmina. Time: 2 m sec/div.

Fig. 88. A portion of the distress call of a starved male of *C. bimaculatus* at 27°C. Time: 2 m sec/div. (Starvation extended to 12 days)

Fig. 89. A single complete pulse of calling song of *Cryllus domesticus* at 30°C. Time: 2 m sec/div.

Fig. 90. Oscillogram showing short pulse of courtship song of *C. domesticus*. Time: 1 m sec/div.

Fig. 91. Oscillogram of a pulse of courtship song of *C. domesticus*. Time: 2 m sec/div.
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Fig. 92. Oscillogram of 3 irregular pulses of full courtship song of Gryllus domesticus at 26°C. Time: 2 m sec/div.

Fig. 93. Oscillogram of a complete pulse of aggressive song of G. domesticus along with an incomplete pulse showing only end part at 30°C. Time: 2 m sec/div.

Fig. 94. The pulse portion of an amateur song of G. domesticus at 30°C. Time: 2 m sec/div.

Fig. 95. Oscillogram of the first pulse of the chirp of a calling song of Gryllodes sigillatus at 34°C. Time: 2 m sec/div.

Fig. 96. Oscillogram of the second pulse of the chirp of calling song of Gryllodes sigillatus at 34°C. Time: 2 m sec/div.

Fig. 97. Oscillogram of the third pulse of the chirp of calling song of Gryllodes sigillatus at 34°C. Time: 2 m sec/div.
Fig. 98. A chirp portion of calling song of Gryllodes sigillatus at 34°C. Time: 2 m sec/div.

Fig. 99. Oscillogram showing pulses of precourtship song of C. sigillatus at 27°C. Time: 2 sec/div.

Fig. 100. Oscillogram of a pulse of calling song of Pteronomobius fascipes in the field at 15°C. Time: 2 m sec/div. An incomplete pulse envelope is also present.

Fig. 101. Oscillogram of two complete pulses of a calling song of P. fascipes in the field at 19°C. Time: 2 m sec/div.

Fig. 102. Same as above at 27°C. Time: 1 m sec/div.

Fig. 103. Oscillogram of two pulses of calling song of P. fascipes at 25°C. Time: 2 m sec/div. Note the sound waves in the interpulse gap.
Fig. 104. Oscillogram of calling song of P. fascipes at 35°C showing 3 complete pulse envelopes. Note 2 incomplete pulse envelopes at both the ends. Sound waves in inter pulse gap are quite distinct. Time: 2 m sec/div.

Fig. 105. Same song as above at the same temperature. Time: 1 m sec/div.

Fig. 106. Oscillogram of one complete and two incomplete pulse envelopes of courtship song of P. fascipes at 25°C. Time: 2 m sec/div.

Fig. 107. Oscillogram of a complete pulse of aggressive song of P. fascipes at 25°C. Time: 2 m sec/div.

Fig. 108. Oscillogram of a complete pulse of calling song of P. fascipes in which the tegminal membranes were cut. Time: 2 m sec/div. Note the other incomplete pulse.

Fig. 109. Oscillogram of a single pulse of calling song of P. fascipes before cutting the tegminal membranes. Time: 1 m sec/div.
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Fig. 110. Calling posture of a male of *Gryllus bimaculatus* in glass chamber (Note the position of hind femur)

Fig. 111. Calling posture the male of *G. bimaculatus* glass jar. The termina are held parallel to the bottom and the abdomen inclined downwards at an angle of 45°.

Fig. 112. Mating in *Gryllus mitratus*.

Fig. 113. A male of *G. mitratus* guarding a female.

Fig. 114. A spermatophore attached to the female *G. mitratus* after copulation.

Fig. 115. The female of *G. mitratus* consuming the spermatophore. Note the abdominal curvature.
Fig. 116. Different Gryllus species attracted to the mercury vapour lamp. Majority consists of *G. domesticus*.

Fig. 117. A fierce combat between males of *G. mitratus*.

Fig. 118. Cannibalism in *Gryllus bimaculatus*

Note the injury caused to male abdomen.