MOLE CRICKETS: ECOLOGY, BEHAVIOR, AND ACOUSTICAL COMMUNICATION
(ORTHOPTERA: GRYLLOTALPIDAE: Scapteriscus)

By

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SANTHI
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I greatly appreciate the efforts of many friends and professors in the Entomology and Civil Engineering Departments who helped me in many ways during the course of my field and laboratory work, and I am grateful to them.
Most graduate students encounter a problem like the one I faced during fall 1970: What should I do for my dissertation? I discussed my problem with many professors; Dr. J. E. Lloyd was helpful with his counseling and his suggestions made me become a field entomologist. I made up my mind to work on the basic aspects of an economically important insect. While I was conversing with Dr. T. J. Walker during December 1970, he pointed out that little was known about mole crickets. I reviewed the literature on mole crickets for a paper at the Florida Entomological Society meeting in fall 1971, and I became convinced that I should work on the basic biology of mole crickets. I was mainly interested in answering questions that were important to the control of mole crickets. Dr. Walker taught me how to go about asking the right kind of question—an important question that can be tackled with available equipment. The work reported here has been presented in five annual meetings: Viz., Florida Turf Grass Association (Gainesville - 1972), Florida Entomological Society (Tampa - 1972, Miami - 1973), and Entomological Society of America (Dallas - 1973, Memphis - Southeastern Branch - 1974). A part of my mole cricket research has appeared in Science (1973, 182: 1278).
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Abstract of Dissertation Presented to the Graduate Council of the University of Florida in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy

MOLE CRICKETS: ECOLOGY, BEHAVIOR, AND ACOUSTICAL COMMUNICATION
(ORTHOPTERA: GRYLLOTALPIDAE: Scapteriscus)

By

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Chairman: Dr. T. J. Walker
Major Department: Entomology and Nematology

The southern mole cricket, Scapteriscus acletus Rehn and Hebard, and the changa, S. vicinus Scudder, are pests of turf and agricultural crops in the southeastern United States. They may have univoltine life cycles. Both species fly during spring and fall in Gainesville, Florida. During 1972, spring collections included 5675 adults (55% acletus) and fall collections had 199 adults (16% acletus). During 1972 and 1973, females comprised 83% of those collected of both acletus (n = 9161) and vicinus (n = 7521). Out of 1844 adult acletus marked and released, 35 were recaptured, proving that at least 2% of adults fly more than once. Three adults were recaptured twice. Recaptures were made up to 6.5 weeks and at distances as great as 0.7 km. S. acletus flight speed was estimated at 7-11 km/hour in a calm night.

Phonotaxis (viz., movement oriented to sound) of flying crickets was demonstrated for the first time, and may provide a new method of control for mole crickets. When calling songs of acletus and vicinus were broadcast through outdoor loudspeakers, large numbers of these two species flew to their respective calling songs. Mated females were more frequently captured than unmated ones, and males were 12% of the catch.
Crickets of three other subfamilies were trapped as they flew to mole cricket calling songs resembling their own. Experiments concerning effects of different parameters of synthetic male acletus sounds on flying acletus proved that acletus discriminated carrier frequency and pulse rate.

Males produced calling songs after sunset for 1.0 to 1.5 hours in specially constructed subsurface chambers. The mean carrier frequency, pulse rate, and intensity of acletus calling songs were 2.7 kHz, 55 pulses per second (p/s) and 69 dB (at 15 cm), and of vicinus were 3.3 kHz, 130 p/s, and 65 dB respectively. Males of acletus and vicinus produced aggressive and courtship songs similar to calling songs with respect to carrier frequency and pulse rate. Sound production by females of Scapteriscus spp. has never been reported, but female vicinus made sounds with energy at frequencies varying from 2 to 6 kHz. Courtship behavior of vicinus included long and short intermittent trills of songs, and tapping of the soil with the forelegs.

Cannibalism was observed once each in captive acletus and vicinus. In both species, 70% of flying adults (n = 113) had an empty crop. Others had plant materials and insect parts.

Although poison baits have been assayed by counting dead mole crickets on the surface, some do die in their burrows.
INTRODUCTION

Mole crickets are subterranean crickets belonging to the order Orthoptera and family Gryllotalpidae. This family has 5 genera and 47 species (Chopard 1968). Mole crickets can be easily distinguished from other crickets by their short anterior legs, with enlarged foretibiae adapted for digging. They are important pests attacking lawns, pastures, and a variety of crops. Although research on the control of mole crickets has been carried on for the last 7 decades, mole cricket problems have continued. The lack of real progress may be due to the lack of basic information on mole cricket biology—especially behavior and ecology. Therefore, I concentrated on these aspects.

Chopard (1968) has recently surveyed the literature on mole crickets. Numerous authors have reported control measures for mole crickets, but only a few have reported their bionomics. I will discuss pertinent literature in the appropriate sections later.

I studied two species of mole crickets: the southern mole cricket, Scapteriscus acletus Rehn and Hebard, and the changa, S. vicinus Scudder. They can be easily identified by morphological characters (Blatchley 1920). In this dissertation, I describe their seasonal life cycles, sound production, acoustical behavior with special reference to phonotaxis, dispersal, food habits, and other aspects of their biology.
Mole crickets occur around the world approximately between latitudes 0° and 50°. The genus *Scapteriscus* occur in the New World, India, and Bangladesh (Chopard 1969). *S. acletus* and *vicinus* are found in the southeastern United States (Fig. 1.1). *S. acletus* is a native species and *vicinus* is probably introduced. *S. vicinus* is known to occur in Cuba, Puerto Rico, Trinidad, and humid sandy areas of the northern part of South America. It appears that *vicinus* was introduced into the United States from the West Indies (Worsham and Reed 1912) circa 1889. Barrett (1902) reported the common belief of Puerto Rican agriculturists that *vicinus* arrived in guano from South America circa 1850. He believed that *vicinus* was present earlier than 1850 in Puerto Rico. Wolcott (1941) failed to find a natural enemy for *vicinus* in Puerto Rico but found a wasp, *Larra americana* Saussure, in Belem, Brazil, and colonized it in Puerto Rico. It appears that *vicinus* is native to northern South America.

Mole crickets are nocturnal and can be found in wet to moist sandy areas where natural vegetation has been considerably disturbed. They are not known from wooded areas. The common habitats of *acletus* and *vicinus* are lawns, golf courses, borders of highways, pastures and annually tilled fields (viz., gardens, nurseries, and crop lands). *S. acletus*, but not *vicinus*, occurs near the edges of lakes, ponds, and streams.
CHAPTER 2
SEASONAL LIFE CYCLES OF MOLE CRICKETS

Three kinds of life cycles have been reported in mole crickets: viz., continuous breeding, univoltine (one generation each year), and semivoltine (one generation each two years). A few workers have carefully studied the life cycles of mole crickets. In tropical Puerto Rico, mole crickets may breed all the year. While studying the life history of vicinus at Mayaguez, Puerto Rico, Van Zwaluwenburg (1918) found that females laid eggs in an insectary every month of the year except December and that all the stages were found in the field at any time of the year.

Hayslip (1943) studied the life cycles of acletus and vicinus in Plant City, Florida, by rearing the mole crickets outdoors in shaded pots covered with screen lids. He concluded that acletus and vicinus were univoltine and that eggs were laid from April to July. He reported that 75% of acletus and 25% of vicinus overwintered as nymphs. The remainder overwintered as adults. He did not mention the size or instar of overwintering nymphs. Tanaka and Yanakigara (1939) studied the seasonal life cycle of Gryllotalpa africana Palisot de Beauv. in Formosan sugarcane fields. They reported that eggs were laid from April to July and adults emerged after 10 months. Several workers have studied the life histories of European mole crickets and all reported life cycles longer than one year. Morales (1940) found in Spain that G. gryllotalpa Linnaeus had one generation each two years. A similar semivoltine life cycle was recorded from East Germany by Hahn (1958), who showed that the nymphs developed into adults after 500 days.
Feeding materials used in rearing of mole crickets affect the developmental period of nymphs. In Germany, Godan (1964) divided the nymphs of *G. gryllotalpa* from the same batch of eggs into two groups: nymphs fed on insect food completed life cycles in 2 years while nymphs fed on vegetable matter had a longer developmental period—"over four years."

**Methods**

Laboratory studies of *acletus* and *vicinus* were conducted in plastic boxes (30 x 20 x 10 cm) partly filled with soil. Single females and male-female pairs were confined in the boxes and fed dry dog food (Purina Dog Chow®). The mole crickets used were captured either at street lights or at broadcasting loudspeakers (for details see page 18). Unless otherwise specified, the mole crickets were caught during spring and early summer 1972. At this time, I started rearing 35 pairs of each of *acletus* and *vicinus*, and 12 to 25 females of *acletus* and *vicinus*. I examined the rearing boxes at one week to six week intervals and made observations on the number of eggs, nymphs, and adults. Assay of mole cricket eggs was by flooding the rearing box with water and filtering the water-suspended soil through a wire screen filter. The eggs were reburied in moist soil by placing all the eggs in a cell 3 cm in diameter.

Field rearing was carried out at the Entomology Farm (Honey Plant). Single pairs of *acletus* and of *vicinus* were confined in clay pots (30 cm diameter x 35 cm height) filled with sterilized soil. The pots were buried 24 cm in the ground and covered with aluminum wire screen secured with a metal band. Field rearing studies were started during spring 1972 using 25 pots containing pairs of *acletus* and 25 pots containing pairs of
A few *acletus* were successfully reared in the field. I observed newly hatched nymphs during October 1972 in 3 pots. These nymphs were produced by 3 females of *acletus* captured 10 July 1972. These nymphs matured as early as the first week of April 1973. During my observation of field pots in winter (January and February 1973), I saw only nymphs with developing wing pads.

**Discussion**

Life cycles of *acletus* and *vicinus* in Gainesville, Florida, are not clearly understood. In my field rearing, adults found in early summer laid eggs in summer that produced adults the following spring; this indicates that some spring adults give rise to spring adults. However, the life cycle may not be as simple as this would indicate. The reason being, adults of *acletus* occur all months of the year, and peaks of flight and singing were found in both spring and fall. I have collected flying *acletus* from 4 November 1972 to 2 January 1973 and 22 May to 24 July 1973. T. J. Walker (unpublished data) censused singing males of *acletus* around Gainesville, Florida, weekly for more than a year at 12 sites and found adults every month.

With the available data, two models of *acletus* life history are worth considering. The first model suggests that the spring flying and singing population produces a small fall population and a major spring population. The progeny of the fall population becomes part of the spring population. The second model is based on the assumption that the fall and spring populations are distinct. In this model offspring of the spring population mature the following spring, and those of the fall population the following fall, with the possibility of two allochronic species.
In the first model, spring or early summer adults of *acletus* lay eggs in late spring or summer. The newly hatched nymphs have two types of development: some develop fast and become adults in fall, most develop slowly and become adults the following spring. The main confusion in *acletus* life cycles concerns the fall population, especially when the fall adults mate and lay eggs. The different possibilities concerning such fall adults are summarized below:

<table>
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<th>Fall Adults</th>
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<td>Mating occurs in fall</td>
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<tr>
<td>Adults do not lay eggs but store sperm in spermathecae and lay eggs in spring.</td>
</tr>
<tr>
<td>Adults lay eggs in fall.</td>
</tr>
<tr>
<td>Mating does not occur in fall. Adult overwinters and contributes progeny along with spring populations.</td>
</tr>
<tr>
<td>Eggs overwinter and hatch in spring, and nymphs become adults in late spring or early summer.</td>
</tr>
<tr>
<td>Eggs hatch in fall, and nymphs overwinter and mature in late spring or early summer.</td>
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I will analyze each of the above possibilities based on the current evidence. In crickets, the calling songs of males attract sexually responsive females and the males mate with the females (Alexander 1967). Singing of males is correlated with mating activities. Singing of *acletus* in Gainesville occurred during fall with a peak in October (T. J. Walker, unpublished data), suggesting that there is mating among fall adults. If mating occurs in fall, the next question is whether the mated (fall) adults lay eggs in fall or not. Hayslip (1943) did not find any egg laying among captive female *acletus* during fall. If eggs are not laid in fall, is it possible for the mated female to store sperm in the spermathecae? T. J. Walker (unpublished data) reports that mated
females of *Gryllus* species can lay fertile eggs for at least two months without further mating; however, no crickets are known to delay ovis- positing for a month or more following insemination. This raises a question: if eggs are laid in fall, do they hatch in fall or spring? The few life cycle studies of mole crickets suggest that the overwintering stages are only nymphs and adults, not eggs. Therefore, if eggs are laid in fall, they probably do not overwinter, but hatch that fall.

My second model proposes that the spring population of *acletus* lays eggs in late spring and summer, and that these eggs give rise to overwintering nymphs. Adults appear in spring or early summer from these nymphs. The fall adults lay eggs in fall that produce overwintering nymphs that become adults the following fall. The spring and fall populations are separated seasonally and do not interbreed in nature. If this model seems unlikely, consider that the most common field crickets of the northeastern United States [*Gryllus veletis* (Alexander and Bigelow) and *G. pennsylvanicus* (Burmeister)] have comparably contrasting life cycles, and were long believed to be a single species.

In the case of *vicinus*, I have circumstantial evidence suggesting that fall females do not lay eggs in fall. I collected 40 female *vicinus* on 12 November 1972 near broadcasting loudspeakers and placed them in 4 pots, 10 females in each pot. I kept these pots outdoors at the Honey Plant farm from 12 November 1972 to 15 April 1973. I found neither eggs nor nymphs after 5 months, but found 20 females. The absence of eggs or nymphs does not prove conclusively that the adults do not lay eggs in fall because one cannot exclude the possibility of cannibalism or that the females were unmated. Under the circumstances explained above, neither model suggested for *acletus* can be excluded for *vicinus*. The
life cycles could be understood by field rearing, especially of fall adults, thereby confirming (or refuting) the models.

Knowledge of life cycles, especially the seasonal distribution of different stages of mole crickets, would be very useful in suggesting effective control procedures. A systematic survey of a pasture for different stages of mole crickets at monthly or shorter intervals would be useful, especially if correlated with rearing studies for *acletus* and *vicinus*.
CHAPTER 3
SOUND PRODUCTION IN MOLE CRICKETS

Mole cricket sounds, especially the male calling songs, are distinctive. If one walks on an irrigated lawn during a spring or summer night, preferably half an hour after sunset, he should hear the long-continued, musical trills of mole crickets from the ground. S. acletus and vicinus calling songs can be distinguished by their trills. S. acletus has a bell-like trill, whereas vicinus has a toad-like trill.

Weiss and Dickerson (1918) compared the male calling song of Gryllotalpa gryllotalpa to "the cry of owl or goat sucker." The calling songs of mole crickets have been used in systematics. Bennet-Clark (1970A) identified a new species of French mole cricket, G. vineae, and reported that it differed from the European mole cricket, G. gryllotalpa, on the basis of calling song. The calling song of G. gryllotalpa was "a quiet dull jarring rumble," with a carrier frequency of 1.5 kHz, while the song of G. vineae was "a loud piercing ringing, like an electric bell" with a carrier frequency of 3.5 kHz. Nevo and Blondheim (1972) reported that two chromosomal forms of G. gryllotalpa from Israel have distinctive calling songs, one with long trills and the other with chirps. Bennet-Clark (1970B) measured the intensities of a calling song of G. vineae at various points and plotted an isobar diagram of the song. By using these data, he was able to calculate the acoustic energy emitted in sound production; and in G. vineae, he estimated the efficiency of conversion of muscular power to acoustic power as about 35%. He discovered that singing
*G. gryllotalpa* and *G. vineae* had horn-shaped burrows with two entrances; furthermore, he speculated that the shape of the burrows enhanced the sound propagation.

Unlike most crickets in which only males make sounds, female mole crickets have been observed to produce sounds (Petrunkewitsch and von Guaita 1901, Baumgartner 1905). Baumgartner (1910) reported the noise of a female *N. hexadactyla* as a loud and distinct chirp. He observed females making these chirps when one individual was approaching another, especially when one was digging a new tunnel. Tindale (1928) described the sound of a caged female Australian mole cricket, *G. ova* Tindale, as "dull pulsating sounds, clearly audible six feet away." The function of female sound production is unknown.

**Methods**

All my observations were made within 15 miles of Gainesville, Florida, from 1972 to 1974. Recordings of mole cricket songs were made with a portable tape recorder (Nagra III®, Kudelski, Paudex-Lausanne, Switzerland) and a microphone (Electro-Voice®, Model 655C), mounted on a camera tripod directly downward over the entrance of the mole cricket burrow and 15-25 cm above the ground (Fig. 3.1). The calling songs of *acletus* (n = 70) and *vicinus* (n = 62) were tape recorded in the field. The following weather factors were recorded after the tape recordings: soil and air temperatures, relative humidity, and light intensity. Soil temperature was taken 3-5 cm deep, near (within 15 cm) the entrance of the mole cricket's burrow. Air temperature was recorded 1.5 m above the ground level. Relative humidity was measured with a psychrometer.
(Bendix Model No. 566) 1 m above the ground. A light meter (Photovolt Corporation Model No. 200) was used to measure the light intensity. The light-sensitive target was aimed directly upward. The sunset time was calculated for Gainesville by using the World Almanac (Long 1969). The time of singing was recorded in Eastern Standard Time which was verified daily before going to the field. The features of mole cricket male calling songs (i.e. intensity, carrier frequency, and pulse rate) were examined in two ways: The intensity of the calling song was measured in the field, 15 cm above the burrow entrance, using a sound level meter (General Radio Model No. 1551-B, Weighing Scale-A, Reference Intensity - 0.0002 dynes/cm²). Carrier frequency and pulse rate were analyzed with a Sonograph (Kay Electric Co.).

The starting times of mole cricket calling songs were recorded in the field. As soon as I heard the first calling songs of acletus and vicinus, I recorded the time. If the first calling song was not followed by two other calling songs of the same species within 5 minutes, I discarded the previously noted (starting) time.

The effects of weather factors on the different parameters of male calling songs in acletus and vicinus were examined using the method of least squares for fitting a multiple regression model (Levy et al. 1974), based on a straight line equation, \( y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 \), where \( y \) = estimated or predicted value of a parameter of calling song (viz., intensity, carrier frequency, and pulse rate), \( b_0 = \) constant, \( b_1...b_3 = \) the estimate or measure of the strength on the effect of \( x_1...x_3 \) on the response \( y \), \( x_1...x_3 = \) the independent variable (i.e. weather factors--soil temperature, air temperature, and relative humidity).
Results and Discussion

Sound production in crickets is generally by tegminal stridulation. There is a scraper on the anterior portion of the inner margin of each forewing and there is a stridulatory file on the under surface of each male forewing. The sound is produced when the scraper of one wing rubs against the file of the other. It is difficult to make observations of singing mole crickets because they are in the soil. It appears that the sound production in acletus and vicinus is similar to other crickets.

On one occasion, I observed a male vicinus producing the calling song in a plastic box without any soil. The wings were moving rapidly and were raised about 15-20° above the thorax. The left wing was over the right wing (unlike what has been reported for other crickets).

The calling songs of acletus can be heard near the borders of ponds and lakes, on the sides of streams, roadsides, fields, and lawns. S. vicinus songs were heard mostly in lawns, pastures, and annually tilled fields.

Calling songs in acletus and vicinus are produced in their burrows in the absence of other members of the same species. With some exceptions, acletus and vicinus begin calling after sunset (Table 3.1). During and after rain, I have heard calling songs of acletus and vicinus at all times of night. I have never heard calling songs of acletus during daylight hours prior to sunset. Except on two occasions (Table 3.1 footnote), vicinus calling songs were heard only after sunset. In most cases, the light intensity was less than 65 lux when calling songs started. The males of acletus and vicinus sang for 1.0 to 1.5 hours nearly continuously. The singing was interrupted occasionally by silent periods varying from 2 seconds to 3 minutes.
Prior to the commencement of singing, the males of *acletus* and *vicinus* open an entrance to their burrows. The entrance is made smooth with the male's tibial dactyls. After working on the burrow entrance, he backs into the burrow, turns around, and starts singing with his abdomen towards the entrance. Males start their songs with short trills of 2-3 seconds. Sometimes they stop singing, turn around, and return to smoothing the entrance. In this manner the burrow walls are made very smooth. Of 10 caged *acletus* observed for singing in the field, 4 closed their entrance after singing. When such was the case, the entrance made on the following evening was often in a new position.

The different parameters of male calling songs of *acletus* and *vicinus* are given in Table 3.2. The distribution of carrier frequency of the calling songs of *acletus* and *vicinus* is shown in Fig. 3.2B. The modal frequency of *acletus* and *vicinus* was 2.7 kHz and 3.2 kHz respectively (Fig. 3.2B). The pulse rates of *acletus* and *vicinus* are dramatically different in the calling songs (Fig. 3.2A, and 3.3A-C).

Regression analysis of the effect of weather factors on the different parameters of male calling songs revealed no correlation between temperatures (soil and air) or relative humidity and intensity or carrier frequencies of the calling songs of either *acletus* or *vicinus* (*P* = 0.05). The pulse rate of *acletus* was found to be a function of soil temperature (Fig. 3.4).

No correlation existed between pulse rate and air temperature or relative humidity (*P* = 0.05). I have never heard the calling songs of *acletus* and *vicinus* below 18°C, in spite of being in the field during cold, but otherwise appropriate, nights.

In addition to the soil temperature, soil moisture was found to
influence the production of calling songs in *acletus* and *vicinus* (see page 13). In an unirrigated tobacco field on 21 May 1973, 4 plots (70 m²) were marked. I randomly selected 2 of these and irrigated them with overhead sprinklers for half an hour during that night. The other 2 plots were left unirrigated. There was no rain during the period when I conducted the experiment. After 24 hours, I found 2 *acletus* and 15 *vicinus* males singing in the irrigated plots, and none in the unirrigated.

In addition to the calling songs, males of *acletus* and *vicinus* produce two other kinds of songs—aggressive songs and courtship songs (Fig. 3.5). The aggressive song is produced in the presence of another male. When a male confronts another male, short trills are produced intermittently. On two occasions, I have observed aggressive singing of *vicinus* in a plastic box. The wings are raised 15-20° above the thorax (as in calling) and contrary to my observation of calling, I saw the right wing above the left wing. After the short trills, the males pushed each other with their tibial dactyls. I could not detect any differences in the aggressive songs of a captive *vicinus* in the presence of a single male *acletus* or a single male *vicinus* (Fig. 3.5A, B).

Males of *acletus* and *vicinus* make a characteristic courtship song in the presence of females. A single male in the presence of a single female produces the courtship song intermittently from 15 minutes to 3 days. I have heard courtship songs of *acletus* in the field at all times of the day (Fig. 3.5C). The courtship songs of *acletus* and *vicinus* are rhythmic sequences of short trills, produced intermittently. The carrier frequencies and pulse rates of these songs are similar to calling. The courtship song of *vicinus* has two phases: the beginning phase of the
song is a long sequence of trills (Fig. 3.5D). This is followed by a sequence of short trills (Fig. 3.5E).

In addition to the male songs (calling, aggressive, and courting), I heard females of vicinus producing short bursts of sound (Fig. 3.3D, E) audible 2 m away. On 8 March 1974, I collected 20 females of vicinus at broadcasting speakers and kept them in a plastic box with 6 cm of moist soil covered with 2 moist paper towels. During the same night I heard dull and short bursts of sound from the plastic box. I saw two female vicinus facing each other on the surface of the paper towels. One of the females raised its wings. During the lateral movement of the wings (same as calling males), a dull sound was produced. The female sound has substantial energy frequencies varying from 2 to 6 kHz, unlike the male sounds which have most of their energy at 3.0-3.5 kHz. The pulse rates vary from 54 to 57 per second compared to 135 in male calling. The pulses are in groups of short duration as in courtship songs.
CHAPTER 4 (SECTION A)  
PHONOTAXIS OF CRICKETS IN FLIGHT

Species Specificity of Male and Female Mole Crickets to the Broadcast Calling Songs Outdoors

Phonotaxis is movement oriented in relation to sound. In crickets and katydids, males produce species-specific calling songs that attract sexually receptive females to them (Alexander 1967). Generally, females move to the calling males either by walking or running.

While I was observing mole cricket flight at a lighted golf course near Gainesville, Florida, in spring 1972, I saw a female _acletus_ land near a burrow entrance where a male _acletus_ was singing. The female ran to the male burrow and entered. I thought the male _acletus_ had attracted the female by its calling song. I tested the hypothesis that flying females were attracted to singing males with a simple experiment on 15 April 1974 (Fig. 4.1). Six female _acletus_ landed near a singing male as compared to one that landed on the control. The control had no calling males. After I had confirmed that flying females were attracted to calling males, I wanted to prove that the flying females were attracted only to the sound of the singing male as opposed to other hypotheses (e.g., male pheromone or infrared radiation from the ground). To test my theory, I broadcast a natural calling song of _acletus_ through an amplifier and a speaker on 21 April 1972. I collected 39 _acletus_ (9 males) in a 3 m² area in 15 minutes. Similarly, I captured 48 _vicinus_ (6 males) and 4 _acletus_ on 24 April 1972 when I broadcast the natural...
vicinus calling song. The mole crickets that flew to the broadcasting speaker were not only females, but also included males.

In preliminary experiments, flying adults of both sexes were attracted to a broadcast sound of a male mole cricket. Orientation to sound occurred in flight. This was the first demonstration of an orthopteran orienting to sound during flight.

I conducted further experiments at a lighted Golf Course (State Highway No. 26, Section 36 of Township R.18E, T9S, 16 km west of Gainesville, Florida) in 1972 and an unlighted field (Green Acre Farm, Department of Agronomy, University of Florida, State Highway No. 241, Section 27 of Township R.18E, T9S, 19 km northwest of Gainesville) in 1973.

This chapter has two sections: The present section describes my experiments relating to the species-specificity of flying acletus and vicinus with the tape-recorded natural male calling songs as well as synthetic sounds simulating the natural calling songs. The next section (B) describes the response of mole crickets to different parameters of synthetic songs.

Methods

My experimental set-up consisted of two independent broadcast systems and 3 large metal funnels (1.2 m diameter). Each broadcast system included battery operated tape recorder (Nagra III and IV), a battery operated audioamplifier (Alton Electronics) and a loudspeaker (Realistic Model No. 40-1228 covered with aluminum screen). Tape recorders and audioamplifiers were housed in a station wagon (Fig. 4.2A). Each speaker was mounted in the center of a funnel and was aimed upward
Funnels were placed 3-30 m apart (Fig. 4.2C). The adults that flew into a funnel (Fig. 4.2D) were collected in a numbered 500 ml jar, screwed to a jar ring soldered to the bottom of the funnel.

The natural calling songs of *acletus* and *vicinus* were tape recorded in the field at 25°C (page 11). The term "natural song" will refer to the taped actual calling songs. Synthetic calling songs were made and tape recorded in the laboratory. Synthetic mole cricket calling songs were produced with electronic equipment described by Mays (1974).

During electronic synthesis of songs, the pulse duration:pulse interval ratio of the song was maintained at 1:1. The actual ratio of pulse duration to pulse interval in 3 songs (25°C) of *acletus* was 3:1, and that of *vicinus* was 1:1. Hereafter, the term "synthetic song" will refer to the taped electronic imitations of mole cricket calling songs. All the synthetic songs were checked for accuracy of pulse rate and carrier frequency.

Broadcasting trials began 15 minutes after sunset and continued until most flights ended an hour later. During each trial, *acletus* and *vicinus* calls were broadcast simultaneously and a trial was stopped when at least one of the 500 ml jars contained 20 or more mole crickets. Tests were made only when the soil temperature was 25 ± 3°C. Soil temperature was measured at 4-6 places near the traps. A predetermined duration was not used for each trial because the number of mole crickets flying varied greatly at different seasons, dates, and times (Fig. 5.1, 5.3). Trials in which no jar yielded as many as 20 mole crickets were disregarded. The jars with trapped mole crickets were detached from the funnels after each trial and replaced with empty ones.

The speaker first used to broadcast a particular song was selected
by using a random number table. In subsequent trials of the same pair of songs, the speakers used were alternated in order to negate position effects. During each trial the third funnel served as a control. At the end of each evening's trials, the mole crickets in each numbered jar were identified (i.e. as acletus or vicinus), counted, and sexed. Sexing was done on the basis of a black spot on the dorsal side of the male forewings—females lack this spot.

To determine whether the females attracted to the broadcast sound were mated or not, I examined 75 acletus and 89 vicinus for sperm in the spermathecae. On more than 5 occasions separated by a week or more, I examined 10 to 25 females that flew into the funnels. These females were immediately placed in containers apart from males. The spermatheca was dissected out, squashed with a drop of water under a cover slip, and examined (450X magnification) for sperm.

The sex ratios of acletus adults that flew into the funnel were compared with those of adults that landed outside the funnels.

Results

At the lighted Golf Course, mole crickets could be seen flying near the lights 100 m from the funnels. When broadcasting began, some of these altered direction and flew towards the funnels. At the unlighted Green Acre Farm, the flying mole crickets could be seen only as they neared the funnels. At both sites, many mole crickets dropped or flew into the funnels. Others landed on the sod nearby. Twenty to 55 percent of the attracted mole crickets landed outside the funnel. Those adults which landed outside the funnel ran in all directions; some of them ran towards the source of the sound (i.e. under the funnels), some of them moved away from the funnels, but all eventually burrowed into the soil. In
favorable weather and season, I have trapped as many as 100 mole crickets per minute at a broadcast sound. Attraction of mole crickets to broadcast sounds at the lighted Golf Course and at the unlighted Green Acre Farm was similar.

I carried out 18 trials with natural songs of both acletus and vicinus. In a total broadcasting duration of 174 minutes, I trapped 975 adults. S. acletus and vicinus were principally attracted to their own songs (Fig. 4.3A). I conducted 15 additional trials with taped synthetic songs for a total of 99 minutes and trapped 887 adults. These results were similar to those with natural sounds (Fig. 4.3B).

Results of trials with synthetic calling songs suggest that carrier frequency and pulse rates of male calling songs may be the important cues to a flying mole cricket making a species-specific response. Ten percent of vicinus females were trapped at acletus songs and 3.4% of acletus females were attracted to vicinus songs. A significantly higher proportion of vicinus females was attracted to acletus songs than vice versa (P < 0.01). For each species, with both natural and synthetic songs, a larger proportion of females than males showed conspecific responses.

In both acletus and vicinus, I found more mated females than unmated ones. Of 75 acletus females examined, 92% had sperm in the spermatheca and I found that 56 of 89 female vicinus had sperm. Percent of females that had sperm in the spermathecae was found to increase as the mole cricket flight season progressed (Fig. 4.4).

While I was broadcasting calling songs of mole crickets, I noticed males and females of a few crickets other than mole crickets in the funnels (sound trap). These crickets did not come to either the control or vicinus traps. Although the three species of crickets captured repre-
sented three subfamilies, their calling songs were similar to that of acletus (Table 4.1). The calling songs of all of these were trills with pulse rates at 25°C within 10 pulses per second of acletus trills. On two occasions, I broadcast the calling songs of Gryllus rubens and acletus simultaneously. G. rubens responded to its own male calling song (Table 4.2). The females of G. rubens (n = 2) had sperm in the spermathecae.

**Discussion**

The attraction of virgin female crickets to male calling songs is easily understood. The attraction of females with sperm in their spermathecae and especially the attraction of males are less easily interpreted. The flights of these individuals (including virgin females) could be interpreted as dispersive flights. The flying adults might use the sexual signaling of males of their species as an indication of a habitat suitable for colonization.

Two kinds of experiments were conducted to test a hypothesis that the mole crickets use the sexual signaling of males as a habitat indicating signal. The first one was to observe the calling male and to record the number and sex of the mole crickets landing near the entrance of the burrows. One would predict that the adults flying towards the sound as a male indicating signal would land near the male burrow and those flying toward it as a habitat indicating signal would land farther away. Therefore, those landing around the entrance of the male burrow should include a significantly higher proportion of females than those landing farther away from the burrow. On two occasions, I sat near the entrance of a male burrow and counted the adults landing within 0.5 m of the burrow.
Six female *acletus* (but no males) landed within this distance of a calling male *acletus* on 15 April 1972. I collected 3 female *vicinus* (but no males) landing within 30 cm of a male *vicinus* burrow on 8 March 1974.

In the second test I collected the adults that were landing outside the sound trap during the broadcasting trials. I compared the sex ratio (SR) of 1308 *acletus* (SR, $\delta : \varphi = 13:87$) that had landed inside the trap with that of 1834 that had landed outside (SR, $\delta : \varphi = 23:76$) and found significant difference ($p = 0.05$). These two experiments support the hypothesis that male mole crickets use the calling song as a sign of suitable habitat.

Morris (1972) demonstrated that male conocephaline katydids were attracted to male calling songs; however, the context was male-to-male aggression over the occupation of territory or broadcasting space. Male-to-male aggression occurs in crickets and has been studied and described, but the approach of cricket males to male calling songs has not been reported (Alexander 1961). I have never observed it in mole crickets.
CHAPTER 4 (SECTION B)
PHONOTAXIS OF MOLE CRICKETS IN FLIGHT

Response of Flying Mole Crickets to Different Parameters of Broadcast Synthetic Songs

In the previous section, I have shown that large numbers of mole crickets could be attracted to broadcast male calling songs in open fields. This technique of attracting flying adults to loudspeakers might prove useful in control of mole crickets--either as a means of destroying crickets or as a means of timing control procedures. Since sound may be tested for the control of mole crickets, parameters of calling songs that were responsible for the attraction were investigated.

Walker (1957) demonstrated that female tree crickets, Oecanthus nigricornis F. Walker, were able to discriminate the pulse rates of synthetic calling songs. Bennet-Clark and Ewing (1967) showed that pulse rate was a critical parameter in the courtship song of Drosophila. Bennet-Clark (1971) reported the biological significance of intensity in the courtship song of Drosophila. Neurophysiologists have shown that auditory systems of crickets have different thresholds of hearing for different frequencies (e.g., Dragsten et al. 1974). All the above studies were carried out under laboratory conditions. Busnel and his coworkers (1963), working with a katydid, Ephippiger spp., outdoors, found that the females responded to all kinds of synthetic signals--any sound that began abruptly worked.
Here I describe my experiments with synthetic songs, systematically varied as to carrier frequency, pulse rate, and intensity, on the responses of *acletus*.

**Methods**

The experiments were carried out at $25 \pm 4^\circ C$ soil temperatures, $25 \pm 5^\circ C$ air temperatures, and relative humidities of $70 \pm 20\%$. The experimental equipment and techniques were similar to those in Section 4 A. However, the following modifications were made. I used three independent broadcast systems and each one consisted of a portable tape recorder (Bell and Howell Model No. 294 and Sony Model No. TC-66 instead of Nagra III and IV), an audioamplifier, and a speaker. A fourth funnel without a speaker served as a control. The synthetic sounds used throughout the experiments had an intensity of $100 \pm 4$ dB, except in experiments where intensity was the parameter tested. In intensity experiments, I regulated the intensities $\pm 1$ dB. The actual calling songs of *acletus* and *vicinus* varied from 42 to 102 dB (Table 3.2). Three sounds were broadcast simultaneously, two test sounds and a standard sound. The standard sound was a synthetic song with 2.8 kHz and 60 pulses per second (p/s) for 1972 and 2.7 kHz and 55 p/s for 1973. The latter standard closely approximated the natural song at $25^\circ C$ (Fig. 3.2, 3.4). The number of mole crickets trapped at a test sound was compared with the number of crickets caught at the standard sound to calculate the relative response. Trials with less than 10 crickets in the standard were discarded. Each synthetic song was tested on at least two nights.
Results

*S. acletus* responded to the standard sound in ten times greater numbers than to a continuous tone of the same frequency. Two hundred seventy *acletus* were captured where the standard was used, as compared to 27 with the continuous tone (2.7 kHz). Results of these trials \( n = 4 \) suggested that amplitude modulations are important to the responses to the calling songs. Since 27 flew to the continuous tone while none flew to the control, it is clear that transients are not essential features for the phonotaxis of flying *acletus*. The number of trapped mole crickets was a function of frequency and pulse rate (Fig. 4.5). Trials \( n = 33 \) in which intensity was the parameter varied trapped 1606 adults. The number of *acletus* trapped approximately doubled for every 6 dB increase up to 106 dB (Fig. 4.6). The control trap generally caught no mole crickets and it never had more than 1.5% of the number of adults in the other three traps.

Discussion

Several features of male calling songs have been suggested to cause species-specific responses in crickets. In the case of mole crickets, Bennet-Clark (1970B) speculated that carrier frequency might be important to flying females. My data demonstrate that carrier frequency and pulse rate are important to species-specific phonotaxis in *acletus*.

*S. acletus* should be able to separate its own songs from *vicinus* songs by pulse rate (Fig. 4.5). There are crickets, other than *vicinus*, occurring in the same habitat with pulse rates overlapping those of *acletus* calls (Table 4.1). Flying *acletus* is able to distinguish the songs of its own males from the songs of these other crickets by carrier frequency (Fig. 4.5).
The number of crickets trapped was approximately doubled for each 6 dB increase. A simple hypothesis fits these data. The sound waves are radiating in all directions from the broadcasting loudspeakers. In general, the sound pressure is halved for each doubling of distance from a sound source. This change is usually expressed as a decrease in sound pressure level of 6 dB. I do not know the exact shape of the sound field around a broadcasting loudspeaker, but if you imagine the sound field produced by the broadcasting loudspeaker to resemble the crown of a tree, then the low intensity sound field would be similar to the crown of a small tree and the high intensity sound field would be similar to the crown of a big tree of the same proportions. According to the principle involved in sound pressure, the diameter of the crown of a tree would be doubled for each 6 dB increase in intensity. If you assume that the mole crickets are flying in a plane and maintaining straight courses, you would expect the catch of mole crickets to double for every doubling of diameter.
Mole crickets fly in large numbers under street lights on warm nights during spring and fall in Florida, but little is known about the flights. Barrett (1902) reported that vicinus in Puerto Rico were observed in flight from 7 to 10 pm, in addition to twilight hours. Beck and Skinner (1967) collected acletus and vicinus at light traps in Tifton, Georgia, from 1 April to 31 October 1966. They trapped 99 acletus, 70 vicinus, and 2 N. hexadactyla. During the first half of the trapping period, their collections were 92% vicinus and in the last half they were 85% acletus. Hayslip (1943) found that acletus and vicinus flight occurred shortly after dark and lasted about an hour. He stated that acletus and vicinus flew in spring and fall and that acletus was predominant in fall.

In this chapter, I describe the dispersal flights of acletus and vicinus with special reference to season, sex ratio, behavior, physiology, range, and air speed.

**Methods**

I made observations on mole cricket flight daily, except on rainy or cold (air < 18°C) days from 10 April to 31 July 1972, and from 22 February to 31 July 1973. I went to the field from 1 November 1972 to 1 February 1973 on those nights when the air temperature exceeded 20°C. I conducted all my experiments at the lighted Golf Course and Green Acre Farm. Weather data were collected (see page 11). I monitored the flying
mole crickets in two ways. My first method was to record all the mole crickets that flew to the broadcasting loudspeakers on a night. My second procedure was to pick up after 10 pm the mole crickets that had flown to street lights at 6 locations in and around Gainesville. Adults collected under the lights and at broadcast sound were identified, sexed, and counted.

I studied the starting time of mole cricket flight and the variation in the number of flying adults during a night by broadcasting. To record the starting time of mole cricket flight, I broadcast the calling songs of *acletus* and *vicinus* immediately after sunset. As soon as 3 or more adults had flown into the funnel, I considered the flight to have begun. To observe the fluctuations of the flying population during an evening, I removed adults from the sound trap at 5 minute intervals.

The air speed of flying *acletus* \( n = 10 \) was observed at the Golf Course on 3 June 1973. The method was similar to that of Arbogast (1965).

An attempt was made to study the wing-beat frequencies of flying mole crickets and temperature of thoracic muscles in the flying adults. A flight mill similar to that of Chambers and O'Connel (1969) was used to study the wing-beat frequencies of mole crickets. Seven female *vicinus* collected 30 April 1973 were tested on the flight mill 1 May 1973. In timing the duration of the flights, I disregarded pauses of 15 seconds or less. Wing-beat frequency was measured with a stroboscopic light (Strobatac, General Radio Model 631-B). The thoracic temperature of flying insects was measured within 30 seconds after they had stopped flying. I pierced the metasternum of the adult with a needle containing a thermocouple and measured the temperature with a Bailey Instrument Co. Model BAT-4 indicator. At the Golf Course, I made measurements of
thoracic temperature of female acletus within 60 seconds of their landing.

Marking, releasing, and recapturing of acletus was carried out from May to July 1974 at the Green Acre Farm to find out whether individuals flew more than once and the distance flown. Flying adults \( n \geq 3000 \) were obtained at broadcasting loudspeakers. I used different colors of acrylic paint to mark different portions of the pronotum to indicate the date, distance, and direction of release. A total of 1844 marked acletus (24% males) were released in various directions. Capturing, marking, and releasing of adults were carried out on the same night. I placed the adults (in groups of 5) in paper cups (10 cm x 5 cm height) during the interval between capture and release to avoid cannibalism or injury to the adults. On a given night, I released the adults at a single distance from a center point, but in various directions. Recapturing was at the center point by broadcasting synthetic songs of acletus. Adults that landed inside the funnel were examined for marks with a portable UV light (Ultra Violet Products Inc. Model UVL-22). The marks were clearly distinguishable by their brilliant fluorescence. The recaptured (i.e. previously marked) adults were marked distinctively and released on the same night from the same distance and direction that they had been previously released.

I tested a hypothesis that mole crickets fly through or above forests. I conducted the experiments in two situations using the broadcasting techniques. In the first one, I selected an area (100 x 200 m), covered with pines and oak trees (> 20 m high) between two open fields. On 22 April 1973, I placed a sound trap at the midpoint of the woods and also in the open field and broadcast vicinus songs for 14 minutes. In the other situation (14 May 1973), I broadcast acletus and vicinus
songs on the roof of McCarty Hall (University of Florida Campus), a three-story building surrounded by lawns and woods.

Results

In Gainesville, Florida, there are two flights of *acletus* and *vicinus*: a major spring flight and a minor fall flight. I captured a total of 5675 adults of which 55% were *acletus* during spring 1972, whereas 199 adults (16% *acletus*) were collected in fall 1972. With a few exceptions, the flight activities of *acletus* and *vicinus* are largely seasonally separated (Fig. 5.1C). During 1973, *acletus* flew from May to July, and *vicinus* flew from March to May. In 11 instances during 1972 and 1973, *acletus* and *vicinus* flew in large numbers (n = 20) on the same night. I have noticed a few adults of both species flying other months. For instance, I have collected *acletus* (n ≤ 9 per night) adults in March and April when *vicinus* flew predominantly. Similarly, *vicinus* (n ≤ 5 per night) adults were found in July when *acletus* was predominant. Fall flights occurred on 4, 7, 11, and 12 November, 5, 6, 7, and 9 December, and 2 January 1973. I collected 32 *acletus* and 167 *vicinus* in these 9 days. Of those collected in November (n = 54), 56% were *acletus*. Of those captured in December and January (n = 145), 99% were *vicinus*.

During my observation (except 31 May 1973), the number of flying females was consistently more than the number of males. I collected 9161 *acletus* and 7521 *vicinus* adults during 1972 and 1973. Of these, 83% were females in both species. Sex ratios of *acletus* and *vicinus* from two sampling techniques are given in Fig. 5.2. Sex ratios of *acletus* collected under light and sound are not significantly different from each other (p = 0.05), while the sex ratio of *vicinus* collected under light was significantly different from the sex ratio of (*vicinus*) adults trapped in the sound (p = 0.05).
Flight activities started immediately after sunset (Table 3.1) and continued for an hour (Fig. 5.3). Adults of acletus and vicinus emerged from the ground. I observed vicinus adults on the surface of the soil soon after sunset. Most of the acletus observed did not come out of the ground until it became dark (light intensity < 20 lux). A few came to the surface soon after sunset.

Some of the acletus and vicinus on the soil raised their tegmina and moved them rapidly. The movements were similar to those observed during noise production (wings moved laterally), but silent. In acletus, the wings were moving fast while the hind and front legs were kept close to the body. The mesothoracic legs were kept wide apart. In addition to the movement of the tegmina, the body was also vibrating. Probably mole crickets raise their body temperature before take-off.

Take-off was not closely observed in acletus, but in vicinus the head and front portions of the body were raised, keeping the front legs close to the head, and the body was pushed into the air by the hind legs. Sometimes vicinus made small leaps ranging from 15 cm to 30 cm for several times before it took off. In some cases, I saw acletus and vicinus making short flights of 0.5-2.0 m.

I have observed landing of both species in the presence or absence of broadcast. I could not detect any differences in the landing behavior of acletus and vicinus. Landing occurred in several patterns at the Golf Course in the absence of broadcast. Some adults landed on the ground smoothly like aircraft; some abruptly crashed to earth. After landing, I observed, mole crickets did one of three things—some (three females) entered a male's burrow, most of the rest dug into the soil, and some flew again.
Mean wing-beat frequency of tethered female vicinus was 806 Hz at 23.5°C (air) and 50% relative humidity. One female flew 45 minutes on the flight mill (Table 5.1). There is no correlation between the duration of flight and the thoracic temperature of the tethered females. The mean thoracic temperature, recorded from the flying acletus outdoors, was 4°C above the ambient (air) temperature (SD = 0.97, Range, 2.0-5.3°C) (Table 5.2).

In the dispersal studies, 2% of marked acletus were recaptured (i.e. flew more than one night) (Fig. 5.4A). Three adults flew more than two nights (Fig. 5.4C). The maximum duration between the release of a marked adult and recapture of the same individual was 6 weeks, proving that some adults fly again during a period of 6 weeks. Some individuals flew about a kilometer (Fig. 5.4B). The air speed of acletus varied from 7.2 to 18 km/hour ($\bar{X} \pm SD = 11.8 \pm 1.1$ km) on a clear night with no wind.

The results of experiments designed to see whether mole crickets could fly through and above woods were positive. I collected 133 vicinus in the sound trap in the middle of the woods and 154 vicinus in the trap in the open field. On one occasion I was hit by flying adults while walking through the woods during broadcasting. I collected 33 acletus and 42 vicinus on top of McCarty Hall, a three-story building. This suggests that at least some adults fly over barriers 20 m high.

**Discussion**

Mole crickets occupy temporary habitats, and therefore flight is adaptive to individuals. The factors causing the mole crickets to fly are unknown. Deficiency of food, crowding of individuals with incipient cannibalism, and physical disruption of habitat might cause the adults
to fly. It appears that proper climatic conditions are necessary for
the flight. I have never seen acletus or vicinus fly below 18°C (soil
and air). For instance, vicinus flight did not occur from 14 March to
30 March 1973 and from 1 April to 12 April 1973 due to cold (soil
temperature < 20°C) and a few rainy days. Although present at the
lighted Golf Course during a few cold nights, I failed to see flying
mole crickets. On many occasions I observed large numbers of flying
mole crickets after the rain, especially after a long dry period. Rain
is one of the important factors determining mole cricket flight.

It seems that presence of proper ontogenic stage (e.g., recently
molted adults) might influence the mole cricket flight (see page 6 to
9). It appears that there were two peaks of flight for vicinus during
1973 (Fig. 5.1C). The first peak (5 March 1973) was probably due to the
overwintering adults that started flying after the warm weather. The
second peak (22 April 1973) might be due to the new adults that developed
from overwintering nymphs. In Puerto Rico, vicinus flew from October to
December (van Zwaluwenburg 1918), but the major flight in Gainesville
occurred during March to May 1973. I was not able to monitor vicinus
flight during 1972.

It is not known what cues are used by mole crickets to start their
flight on an evening. Light intensity might play a role. I have never
seen mole crickets fly at a light intensity more than 65 lux. I found
the flight of acletus occurring after the flight of vicinus (Table 3.1,
Fig. 5.3). Similarly, singing of acletus started after vicinus started
their songs (Table 3.1). Lloyd (1966, 1969) and Farnworth (1973) observed
that fireflies, Photinus species, flew at a specific time during night.

Physiological studies on energy expenditure and source of fuel used
for flight are some of the areas that would help to elucidate mole cricket flight.

Dispersal studies suggest that reinfestation of a treated field could occur several times in the same season. Mole crickets fly from one field to another. It seems that a woodland around a field would not prevent its colonization. Mole crickets would fly either through or above the woods. Reinfestation of treated golf courses, even though they are not lighted, could occur from a nearby infested pasture.

Unless the mole cricket flight is clearly understood, control procedures may prove ineffective.
Numerous reports describe mole cricket damage to a variety of crops. Hayslip (1943) pointed out that the damage caused to the plants was of two sorts: (1) Direct damage of plants by feeding on stems or roots; (2) Indirect damage by uprooting the plants. Blatcheley (1920) reported that the crop of vicinus contained plant materials and soil particles. He did not mention how many crops were examined or their source. Only a limited amount of information is available on the food habits of other mole crickets (Godan 1961, 1964, 1967; Lefroy 1909).

This chapter describes by attempt to get direct quantitative evidence on the food habits of mole crickets in the field.

Methods

I examined the crop contents of 79 adult acletus and 63 adult vicinus. Adults were classified as flying and nonflying. Flying adults had flown into sound traps. Nonflying adults were either singing males or individuals that were crawling on the surface of the soil during a rainy day. The captured mole crickets were dissected within 2 hours and contents of the crop were examined.

Results and Discussion

Crops of acletus and vicinus had various plant materials (e.g., rootlets, seed coats, grass blades) and insect parts (e.g., setae,
cuticle, antennae, cerci, legs). Of 25 _acletus_ having food in the crop, 11 had insect parts, 1 had plant materials, 2 had both, and in the rest the material could not be identified.

The unidentified material was a semisolid dark brown substance. Of 19 _vicinus_ having food in the crop, 3 had insect parts, 10 had plant material, 4 had both, and 2 had only unidentified material. I noticed that 90% of the flying adults had empty crops distended with gas (Table 6.1). On three occasions, I found nematodes belonging to the family Thelastomatidae. Dr. W. R. Nickle (personal communication) did not consider these nematodes (probably genus _Cameronia_ Basir 1948) would be pathological to mole crickets.

On two occasions I have seen cannibalism. Once I saw a captive female _vicinus_ devouring a newly hatched nymph. Another time I found a partly eaten living adult _acletus_ when I kept more than 10 adults in a plastic box overnight.

My observations suggest that food storage may occur in mole crickets. Under laboratory conditions, I kept a _vicinus_ in a plastic cup (12 cm diameter x 15 cm height) for more than a week and placed (>10) wheat kernels on the surface of the soil. I found a few wheat kernels at the bottom of the cup in an oval chamber.
CHAPTER 7
OTHER ASPECTS OF BIOLOGY

Very little information is available on the burrowing habits of mole crickets. *S. acletus* and *vicinus* burrow deep (about 1 m) into the soil (Hayslip 1943). Tappan (1963) did not find any surface burrowing below 18°C. Mating behavior in *G. Gryllotalpa* (Boldyrev 1915) and in *N. hexadactyla* (Baumgartner 1905, Alexander and Otte 1967) has been described. Courtship and mating behavior is unknown in *Scapteriscus* species.

Here I report my observations with reference to (a) special chambers found in *acletus* and *vicinus* burrows, (b) courtship behavior, and (c) effects of insecticides on mole crickets.

Methods

Burrows of *acletus* and *vicinus* were observed in the laboratory. I examined the burrows in the rearing containers by cutting the soil vertically into thin slices with a knife. Slicing of soil facilitated finding special chambers of the adults. I studied the burrows of singing males in the field. Castings of male burrows were made with a mixture of 60 g of (Carter's) household cement and 100 ml of acetone.

On 30 April 1973, I observed the courtship behavior of *vicinus* for 2 hours in the laboratory. A male and a marked female were confined in a transparent plastic box with 3 cm of moist soil. Observations were made through the bottom of the container that was placed in an elevated
position. Similarly on three occasions I observed the courtship behavior in *acletus* for 15 minutes each.

An insecticidal test was carried out in a pasture to test the efficacies of three chemical baits (Diazinon, Dursban, and Dylox) on mole crickets. I selected 12 plots (9 m² each) separated by 1 m border. The treatments of baits and control (no bait) were randomized and replicated 3 times. I irrigated the plots for 3 days before applying the baits (1.7 kg active ingredient per hectare) on 17 September 1972. The dead mole crickets were counted on the surface of the soil for 4 days early in the morning (before 7 am). On 21 September, I drenched an area of 1 m² in each plot with 1% pyrethrum to sample the mole cricket population in the treated and control plots. I counted the mole crickets that emerged from the soil within 15 minutes. On the same dates, I observed the efficacy of Dursban bait outdoors in 4 pots (0.3 m diameter) with wheat kernels as food. The bait (2.3 kg active ingredient per hectare) was applied on the surface of the pots. The fourth was a control. Each pot had 2 large nymphs of *vicinus*.

**Results**

I found special egg chambers in the rearing containers. *S. acletus* and *vicinus* constructed ellipsoidal chamers and laid their eggs in these cells. The egg chambers of *vicinus* (n = 7) varied in their long axis from 2.6 to 4.5 cm ($\bar{X} \pm SD = 3.32 \pm 0.71$ cm) and in their width at widest point from 1.5 to 2.6 cm ($\bar{X} \pm SD = 2.21 \pm 0.38$ cm). Similarly a single *acletus* chamber had a length and width of 2.4 and 1.8 cm. The height of these egg chambers was about 2.0 cm. Hayslip (1943) observed similar egg chambers.
After assaying the number of eggs in the laboratory, I placed them in an artificial egg cell. Two of the batches of eggs that were so treated were attacked by fungus. Mole crickets may have some mechanism that prevents fungus from destroying the eggs, since I found no molded eggs in chambers constructed by captive mole crickets.

On more than 15 occasions, I have examined the singing burrows of acletus and vicinus both in the laboratory and in the field. The two species have similar singing burrows. Each burrow has a 3-5 cm singing chamber (bulb) 3-5 cm below the soil. This bulb has 3 openings; a narrow passage that opens at the ground surface and two side tunnels that are connected to other burrows. The narrow passage (3 cm diameter) that leads to the surface opening from the bulb was 5-7 cm long and had an angle of 30-45° to the ground level. Bennet-Clark (1970B) found special chambers for singing in G. gryllotalpa and G. vineae. These chambers differ from those of acletus and vicinus by having two surface entrances.

Many insecticides have been screened for mole crickets during the last 3 decades, but it is very difficult to evaluate the efficacy of an insecticide for soil arthropods. One of the methods used in the past was to count the number of dead (or morbid) insects on the surface after the application of baits or chemicals. In the case of mole crickets, Habeck and Kuiter (1964) have taken into consideration the burrowing activities of adults, in addition to the above counting methods.

The results of experiment (Table 7.1) show no significant differences among the 3 treatments. Furthermore, there were live mole crickets found under the soil surface. In the pot experiments I found dead nymphs, not only on the surface (n = 3), but also underground (n = 3). There was no
mortality in the control pot.

It is clear that mortality occurred not only on the surface, but also under the soil. Therefore, counting the dead mole crickets on the surface does not represent the true efficacy of a bait or chemical. Screening of insecticide for mole crickets in the field should be done with caution. Assaying the live mole crickets after the experiments, measuring the surface burrows, counting the dead mole crickets on the surface (and if possible digging the treated plots for dead ones in the soil) are some methods that could be used for evaluating the value of a chemical for mole cricket control.
In Gainesville, Florida, the biology of mole crickets, *Scapteriscus acletus* and *S. vicinus*, was studied during 1972 and 1973. While I was studying their acoustical behavior, I found the females landing near the calling males and entering into their burrows (Fig. 4.1). When calling songs of *acletus* and *vicinus* were broadcast through outdoor loudspeakers (Fig. 4.2), large numbers of these two species flew to their respective calling songs (Fig. 4.2). Phonotaxis of orthopteran was demonstrated in flight for the first time. Phonotaxic attraction of large numbers of mole crickets may be used as a control, either as a means of destroying crickets or as a means of timing the control procedures. The mole crickets so attracted would not only include females, but also males (Fig. 5.2).

There are several problems in using sound as a control. I will analyze three such problems briefly. First, the sound trap—the equipment used to attract mole crickets (Fig. 4.2B)—is not effective on the nonflying adults and nymphs, and even those adults that do fly, do so only at a special season. Adults of *acletus* and *vicinus* only fly during spring and early summer, and fall (Fig. 5.1). Furthermore, the adults fly only in favorable weather conditions during the flight season (e.g., days in which soil and air temperature < 20°C, flights do not occur). Therefore, sound traps can be used only on those days when *acletus* and *vicinus* fly.
The second problem using sound as control was the efficiency of the present sound trap. I was able to trap 20-55% of the "attracted" mole crickets into the funnel, while the remainder missed the funnel and burrowed into the trapping area. To increase the efficiency of the sound trap, the diameter of the capturing area should be increased. Otherwise, the landing adults would be concentrated around the trapping area causing serious damage.

The third problem with using sound as a control was the effective range of sound trap. The diameter within which the mole crickets can be influenced by several factors, only some of which have been investigated. For instance, an intensity of 112 dB attracted the maximum number of adults (Fig. 4.6), but it was not known from what distance they flew.

A part of my research dealt with methods to increase the number of attracted mole crickets to the sound trap. I conducted a series of experiments systematically varying different parameters of calling songs on the response of flying acletus. The number of mole crickets trapped was found to be a function of carrier frequency and pulse rate (Fig. 4.5). These results proved that the catch of mole crickets could be maximized by using appropriate parameters of calling songs (e.g., in acletus, the maximum numbers were trapped with a sound of 2.7 kHz, 55 pulses per second, and 112 dB).

I also studied the appropriate time for broadcasting. Since acletus and vicinus sang and flew after sunset (Fig. 5.3, Table 3.1), broadcasting should be started no later than 15-20 minutes after sunset and could be ended 30-45 minutes later.

I effectively put the sound trap to use in studying the other aspects
of mole cricket biology. For instance, the dispersal of mole crickets was studied with marking, releasing, and recapturing methods (Fig. 5.4), however, the recapturing efficiency was only 2% and this proved that at least 2% of the acletus flew more than one night. It seems that a considerable number may be flying more than once. Some individuals flew up to 6 weeks for the second time. It is probable that some females could lay their eggs and start flying again. Some individuals flew more than 0.7 km. It appears that the flight range of mole crickets in favorable weather and wind may exceed a distance of 5 km. These results suggest that recolonization of a treated pasture by flying adults could occur. Furthermore, the same pasture could be reinfested several times during the flight season.

While examining the crop contents of mole crickets, I found 90% of the flying adults had an empty crop (Table 6.1). These results suggest that upon arriving in a new habitat, the "landed" adults could cause severe injury by feeding on the plants.

Finally, studies on the effectiveness of the chemical baits on mole crickets showed that some mole crickets die not only on the surface, but also inside their burrows (Table 7.1). These results would indicate that counting dead or morbid mole crickets on the surface alone would not measure the effectiveness of a chemical.
Table 3.1. Starting time of singing and flight in *acletus* and *vicinus*.

<table>
<thead>
<tr>
<th>Species</th>
<th>Days observed</th>
<th>Minutes after sunset</th>
<th>Serial No.</th>
<th>Days observed</th>
<th>Minutes after sunset</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>SD</td>
<td>Range</td>
<td></td>
</tr>
<tr>
<td>acletus</td>
<td>17</td>
<td>27</td>
<td>8</td>
<td>11 to 45</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>vicinus</td>
<td>25</td>
<td>15</td>
<td>7</td>
<td>-17 to 31</td>
<td>28</td>
</tr>
</tbody>
</table>

On 31 March and 6 June 1973, *vicinus* sang 17 and 2 minutes before sunset.

Means are significantly different (p = 0.05).
Table 3.2. Characters of male calling songs in *Scapteriscus* species, 18-32°C (*n* = total number of calling songs examined for the parameter).

<table>
<thead>
<tr>
<th>Parameter of calling songs</th>
<th>acletus</th>
<th>vicinus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intensity (dB at 15 cm)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>52</td>
<td>40</td>
</tr>
<tr>
<td>$\bar{X}$</td>
<td>68.5</td>
<td>65.4</td>
</tr>
<tr>
<td>SD</td>
<td>12.8</td>
<td>6.0</td>
</tr>
<tr>
<td>Range</td>
<td>42-106</td>
<td>53-74</td>
</tr>
<tr>
<td><strong>Carrier frequency (kHz)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>70</td>
<td>62</td>
</tr>
<tr>
<td>$\bar{X}$</td>
<td>2.62</td>
<td>3.20</td>
</tr>
<tr>
<td>SD</td>
<td>0.14</td>
<td>0.38</td>
</tr>
<tr>
<td>Range</td>
<td>2.4-3.0</td>
<td>2.8-3.6</td>
</tr>
<tr>
<td><strong>Pulse rate (pulses/second)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>70</td>
<td>62</td>
</tr>
<tr>
<td>$\bar{X}$</td>
<td>54.7</td>
<td>135.9</td>
</tr>
<tr>
<td>SD</td>
<td>4.6</td>
<td>23.2</td>
</tr>
<tr>
<td>Range</td>
<td>40-60</td>
<td>105-168</td>
</tr>
</tbody>
</table>
Table 4.1. Attraction of other flying crickets to broadcast songs of *acletus* (60 or 55 pulses per second, 2.7 kHz).

<table>
<thead>
<tr>
<th>Subfamilies and species</th>
<th>Number attracted</th>
<th>Calling songs of attracted species (25°C)</th>
<th>Source of <em>acletus</em> song</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>♂    ♀   Total</td>
<td>p/s   kHz</td>
<td></td>
</tr>
<tr>
<td>Gryllinae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Gryllus rubens</em></td>
<td>10   25   35</td>
<td>55    4.8</td>
<td>Natural and Synthetic</td>
</tr>
<tr>
<td>Oecanthinae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Oecanthus celerinictus</em></td>
<td>6    11  17</td>
<td>65    3.8</td>
<td>Synthetic</td>
</tr>
<tr>
<td>Nemobiinae</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Neonemobius cubensis</em></td>
<td>0    8   8</td>
<td>55    7.3</td>
<td>Synthetic</td>
</tr>
</tbody>
</table>
Table 4.2. Species specificity of male calling songs in *Gryllus rubens* (total of 2 trials) (*p/s* = pulses per second).

<table>
<thead>
<tr>
<th>Species and sex trapped</th>
<th>Number trapped</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G. rubens song</td>
</tr>
<tr>
<td></td>
<td>(4.8 kHz, 55 p/s)</td>
</tr>
<tr>
<td><em>G. rubens</em></td>
<td></td>
</tr>
<tr>
<td>♂</td>
<td>3</td>
</tr>
<tr>
<td>♀</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
</tr>
<tr>
<td><em>acletus</em></td>
<td></td>
</tr>
<tr>
<td>♂</td>
<td>0</td>
</tr>
<tr>
<td>♀</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 5.1. Wing-beat frequency of female *vicinus* (n = 7) at 23.5°C air temperature and 50% relative humidity.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Duration of flight (minutes)</th>
<th>Wing-beat^a/ frequency</th>
<th>Thoracic temperature after flight (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>17</td>
<td>806</td>
<td>29</td>
</tr>
<tr>
<td>SD</td>
<td>14</td>
<td>69</td>
<td>2</td>
</tr>
<tr>
<td>Range</td>
<td>3-45</td>
<td>670-890</td>
<td>27-32</td>
</tr>
</tbody>
</table>

^a^ = per minute
Table 5.2. Thoracic temperatures of female *acletus* recorded soon after the adults landed at the Golf Course.

<table>
<thead>
<tr>
<th>Date of observation (1972)</th>
<th>n</th>
<th>Relative humidity (%)</th>
<th>Temperature (°C)</th>
<th>Thoracic temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Air</td>
<td>Soil</td>
</tr>
<tr>
<td>21 May</td>
<td>5</td>
<td>65</td>
<td>24.0</td>
<td>25</td>
</tr>
<tr>
<td>4 June</td>
<td>2</td>
<td>66</td>
<td>25.0</td>
<td>25</td>
</tr>
<tr>
<td>4 June</td>
<td>2</td>
<td>66</td>
<td>24.5</td>
<td>25</td>
</tr>
<tr>
<td>24 June</td>
<td>4</td>
<td>78</td>
<td>26.0</td>
<td>--</td>
</tr>
<tr>
<td>1 July</td>
<td>2</td>
<td>83</td>
<td>28.0</td>
<td>27</td>
</tr>
</tbody>
</table>
Table 6.1. Status of crop in flying and nonflying acletus and vicinus.

<table>
<thead>
<tr>
<th></th>
<th>Number of adults examined</th>
<th>Percentage to the total examined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>crop empty</td>
</tr>
<tr>
<td><strong>Flying adults</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>acletus</em></td>
<td>69</td>
<td>74</td>
</tr>
<tr>
<td><em>vicinus</em></td>
<td>44</td>
<td>89</td>
</tr>
<tr>
<td><strong>Nonflying adults</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>acletus</em></td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td><em>vicinus</em></td>
<td>19</td>
<td>26</td>
</tr>
</tbody>
</table>
Table 7.1. The effect of insecticidal baits on mole crickets.

<table>
<thead>
<tr>
<th>Treatments (5% baits--1.7 kg Al/Hectare)</th>
<th>Dursban</th>
<th>Dylox</th>
<th>Diazinon</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>Number dead on the surface</td>
<td>Number alive after 4 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Replication</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

= active ingredient

= surface area of each plot was 9 m$^2$. 

= an area of 1 m$^2$ was sampled in each plot at random. To calculate the number of alive mole crickets in each plot, multiply each number by 9.
Figure 1.1. Distribution map of *Scapteriscus acletus* (A) and *S. vicinus* (B) in United States. The predicted distribution is shaded, and the points show county records. Singing data are from Dr. T. J. Walker.
Figure 3.1. The male calling songs of acletus and vicinus were recorded in the field with a portable tape recorder (T) and a microphone (M) mounted on a camera tripod (Tp). The burrow (B) of singing male is directly below the microphone.
Figure 3.2. (A) The relation of pulse rate to carrier frequency in acletus and vicinus male calling songs (p/s = pulses per second). The vertical line indicates the total variation of a given pulse rate, the broad portion of the line is 2 SE on each side of the mean.

(B) The carrier frequency of acletus and vicinus songs. The numbers above the bars indicate the actual number of calling songs having that particular frequency. The height is the number of songs expressed as a percent of the total songs of that species examined for carrier frequency.
Figure 3.3. Audiospectrograms of male and female songs of mole crickets.

(A) Calling song of acletus at 25°C (soil temperature)

(B) Calling song of vicinus at 25°C (soil temperature)

(C) Calling songs of acletus and vicinus at 25°C (viz., A + B)

(D,E) Female sounds of vicinus at 26°C (air temperature)
Figure 3.4. The effect of soil temperature on the pulse rate of *acletus* (n = 70) and *vicinus* (n = 62) male calling songs. The regression lines are calculated on all individual values. The vertical lines show the range on each side of mean (p/s = pulses per second).
Figure 3.5. Audiospectrograms of aggressive and courtship songs of mole crickets. The temperatures (soil and air) are given for each song.

(A) Aggressive sounds of *vicinus* in the presence of a male *vicinus* at 24 and 26°C

(B) Aggressive sounds of *vicinus* in the presence of a male *acletus* at 24 and 26°C

(C) Courtship sounds of male *acletus* at 27 and 24°C

(D,E) Courtship sounds of male *vicinus* at 25 and 25°C
Figure 4.1.  (A) Mole crickets could be seen flying near the lights.  
(B) Flying female *acletus* landed near the entrance to the burrow where male *acletus* was singing.
Figure 4.2. (A) Broadcasting electronics used in outdoor experiments. A pair of portable tape recorders (Tr) and a pair of portable amplifiers (Am) were housed in a station wagon.

(B) The funnel (Fn) along with a speaker and a jar (Ja) is referred to as a sound trap.

(C) The sound traps were placed 3-30 m apart and the control (Cn) trap had no speaker (Sp).

(D) Attraction of flying mole cricket (Mc) to the broadcasting outdoor loudspeaker.

(E) Tethered acletus flying in the laboratory.
Figure 4.3. Specificity of response of flying acletus and vicinus to broadcast recordings of (A) natural and (B) synthetic calling songs. Crickets captured in traps broadcasting conspecific songs are indicated by black bars. Others are indicated by open bars. Each bar shows the percentage of the total number of a sex and species that was captured by traps during the trials with natural songs or during the trials with synthetic songs. The number of individuals is indicated above each bar (p/s = pulses per second).
Figure 4.4. The proportion of females in acletus and vicinus that were mated at various times during the flight season. The numbers above the bars indicate the total number of females examined for sperm in the spermathecae on that date.
Figure 4.5. The response of flying acletus to synthetic sounds that were systematically varied in frequency (A) and in pulse rate (B). A standard sound—synthetic acletus with 2.8 kHz, 60 pulses per second (p/s) for testing frequency; 2.7 kHz, 55 p/s for testing pulse rates—was taken as a reference sound. The number of crickets trapped in the standard sound (0) was taken as 100% response. The relative response was computed as a percentage of those captured at the standard sound. Vertical bar is 2 SE on either side of the mean. A total of 416 mole crickets was trapped in 16 frequency trials, and 843 mole crickets in 24 pulse rate trials.
Figure 4.6. The response of flying acletus to various intensities. All trials used the same synthetic acletus (2.7 kHz, 55 pulses per second) sound. The reference sound was 100 dB intensity and the number of mole crickets trapped in the standard (0) intensity was taken as 100% response. Relative response is the number of mole crickets trapped as a percentage of those captured at the standard intensity. (0) = result of a single trial with a different speaker. The dotted line represents a doubling of the number of mole crickets trapped for each 6 dB increase in intensity. Vertical bar is 2 SE on either side of mean.
Figure 5.1. The flight activities of *acletus* and *vicinus* monitored by broadcasting technique during 1972 (A), and 1973 (C). The relative capture is the number of *acletus* or *vicinus* captured on a particular date as a percent of the total capture of that species during the season. During 1972-1973 (B), a total of 199 adults was captured. The nights on which both *acletus* and *vicinus* flew are shown by arrows.
Figure 5.2. Sex ratio in *acletus* (2A) and *vicinus* (2B) collected under light (LIGHT) and at the broadcasting loudspeakers (SOUND). The numbers above the bars are the actual numbers collected. The relative capture is the number captured of a particular sex by a particular method during a year expressed as a percent of the total capture of that method and year.
Figure 5.3. Fluctuation in the population of flying acletus and vicinus during a night determined by broadcasting techniques. The number trapped is the number of mole crickets collected in the sound trap during a 5 minute period. Arrow shows the sunset time. Vertical bar is 2 SE on either side of mean. Assay for acletus population was made during 4 days and assay of vicinus was made on 20 April 1974.
Figure 5.4. Marking, releasing, and recapturing of acletus were carried out during May to July 1973. A total of 1844 marked adults were released in the field (4A) and 2% of the adults were recaptured (4B). Some adults (n = 35) flew more than one night and 3 flew more than 2 nights (4C). The zero day is the date of marking and releasing in the field. The number above the bar is the actual number of males and females used. Relative capture is the total number of those numbers of that sex released. Signs (e.g.,▼) of the same type represented a single individual that was captured thrice.
LITERATURE CITED


BIOGRAPHICAL SKETCH

S. M. Ulagaraj (known as Raj) was born on 6 March 1944 at Tuticorin, (Tamil Nadu State), India. Raj completed his high school education in 1959 at the end of eleven years of schooling. In May 1964, he graduated from the College of Agriculture, University of Madras. He served in the Department of Agriculture, Government of Madras, as Research Assistant for four years. He was awarded the Government of Madras Scholarship during 1968-70 to pursue his graduate studies. In August 1970, he received his Master's degree in Entomology at the Indian Agricultural Research Institute, New Delhi 110012. Raj has worked toward the Doctor of Philosophy degree in the Department of Entomology and Nematology from September 1970 and has been employed as a graduate teaching and research assistant during his graduate training. He is a member of several scientific societies. Raj won two awards at the Florida Entomological Society annual meetings for his research papers on mole crickets.
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Thomas J. Walker, Chairman
Professor of Entomology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

James E. Lloyd
Professor of Entomology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Dale H. Habeck
Professor of Entomology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Harvey L. Cromroy
Professor of Entomology
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

[Signature]
Robert E. Dohrenwend
Assistant Professor of Botany

This dissertation was submitted to the Graduate Faculty of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy in Agriculture.

August, 1974

[Signature]
Dean, College of Agriculture

[Signature]
Dean, Graduate School