ECOLOGY OF THE TAWNY MOLE CRICKET, *Scapteriscus vicinus* (ORTHOPTERA: GRYLLOTALPIDAE): POPULATION ESTIMATION, SPATIAL DISTRIBUTION, MOVEMENT, AND HOST RELATIONSHIPS

BY

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

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Scapteriscus vicinus is the most important pest of turf and pasture grasses in Florida. The subterranean lifestyle and extreme mobility of these insects make ecological and behavioral studies difficult. Lack of a suitable sampling technique has made investigation of mole cricket population dynamics impossible. Evaluations of chemical controls have been flawed. This study develops a method of correlating sample results with true population density and provides the first quantitative information on spatial distribution and movement patterns of mole crickets.

Three basic techniques for sampling mole crickets were compared: soil flushes, soil corer, and pitfall trapping. No statistical difference was found between the soil corer and soil flushing. Soil flushing was shown to be more sensitive to changes in population density than pitfall trapping. No technique was effective for sampling adults.

Regression analysis provided a means of adjusting for the effects of soil moisture and showed soil temperature to

be unimportant in predicting efficiency of flush sampling. The curve of predicted efficiency vs. soil moisture was logistic in shape, asymptotic to 0% and 100% efficiency, with 50% and 95% efficiency predicted at 13.3% and 19.0% soil moisture, respectively.

Cesium-137 was used to label females for subsequent location underground. Comparison of mean distance to nearest neighbor with the distance predicted by a random distribution model showed that the observed distance in the spring was significantly greater than hypothesized (Student's T-test, $p < .05$). Fall adult nearest neighbor distance was not different than predicted by the random distribution hypothesis.

Mole cricket surface movement was studied using linear pitfall traps and pitfall arenas. Movement patterns differed seasonally. Warm season (i.e. August) movement occurred mostly between sunset and sunrise (77% of pitfall captures). In October, 76% of captures occurred between sunrise and sunset. Factors increasing movement were population density, nymphal size, and rainfall. Ground cover had little effect on movement.

Mole crickets preferred bahiagrass over any variety of Hemarthria altissima, but Hemarthria var. floralta was not resistant to or tolerant of mole cricket damage. No difference in growth rate could be found among nymphs fed bahiagrass, bermudagrass, floralta, globe sedge, or carpet grass.

CHAPTER I
INTRODUCTION

The tawny mole cricket, Scapteriscus vicinus Scudder, is the most important pest of turf and pasture grasses in Florida. The tremendous amount of damage attributed to these insects in recent years (Walker 1985) has generated strong interest in development of control measures. Effective application of insecticides for control of the highly mobile, subterranean mole cricket is difficult and generally unfeasable economically for pastures (Short and Koehler 1977, 1979). This lack of satisfactory chemical control, along with the knowledge that these pests are introduced from South America where they are neither damaging nor abundant (Walker and Nickle 1981), has made biological control seem a most promising area of research for long-term solutions to the problem.

Any realistic approach to the introduction of natural enemies for control of mole crickets requires that some of the gaps in current knowledge of the ecology of these insects be filled. Detailed knowledge of seasonal population trends, distribution, and habitat preference is invaluable when selecting natural enemies for importation and provides the basis for decisions on timing of releases and release site location. That this knowledge is currently

lacking is largely a result of difficulties encountered in sampling mole crickets in the field, difficulties that also prevent accurate evaluation of control measures, whether chemical or natural.

The purpose of this study was to provide basic information about the ecology of mole crickets in the field. Specific objectives were

1. Develop a reliable technique for sampling mole crickets in turf and pasture.
2. Design a sampling program for estimating field populations of S. vicinus.
3. Investigate spatial distribution of S. vicinus in the field.
4. Analyze relationship of grass type or other ground cover to S. vicinus populations.

CHAPTER II
FIELD SAMPLING AND POPULATION ESTIMATION OF THE TAWNY MOLE CRICKET, Scapteriscus vicinus (ORTHOPTERA: GRYLLOTALPIDAE)

Introduction

The tawny mole cricket, Scapteriscus vicinus Scudder, is the most important insect pest of turf and pasture grasses in Florida. It is also found in other southeastern states from South Carolina to Louisiana and is of increasing concern to turf and forage managers throughout the region. The tremendous amount of damage attributed to this insect in recent years (Walker 1985) has generated strong interest in development of both short term (i.e. chemical) and long term (cultural, biological) control measures.

One major obstacle to evaluation of potential control measures (and, in fact, to any quantitative study of mole crickets) is the lack of an effective sampling technique. Attempts at field sampling of mole crickets have included such methods as poisoning (Short and Koehler 1979), estimation of surface burrowing (Schroeder 1941, Walker et al 1982), pitfall trapping (Lawrence 1982), and soil flushing (Short and Koehler 1979, Walker 1979). All have suffered from the same shortcomings -- extreme variability in results, even with known populations, and lack of any

known correlation between numbers captured and actual field density. Williams and Shaw (1982) developed a soil coring device for sampling mole crickets that seemed to provide a method of taking an absolute sample in the field, but they conducted no field tests of efficiency.

This study was designed to evaluate the accuracy of the most commonly used sampling technique - soil flushing using an aqueous solution of either soap or insecticide. Evaluation was approached in two ways, first by comparing flush sampling with soil core sampling in a series of field samples and second by repeated sampling from a confined population of known size under varying conditions.

Materials and Methods

Field Comparison

The tractor-mounted soil coring device developed by Williams and Shaw removes a core 32.5 cm diameter x 48 cm maximum depth. Cores extracted for this study were ca 36 cm depth so that they would fit into 19-liter plastic buckets for transport to the laboratory where the mole crickets were sifted out.

Flushing solutions were 15 ml of either Joy® dishwashing liquid or synergized pyrethrins (1.2% pyrethrins and 9.6% piperonyl butoxide) in 4 liters of water. This solution was poured over the ground in a circular area ca. 32 cm in

diameter, and only those crickets surfacing within the area were counted.

A total of 50 samples were taken with each method, 20 on 2 Sep 1982 at J & E Farm near LaCrosse, FL, and 30 on 16 Sep 1982 at Pat Baker's farm near Hawthorne, FL. Sampling procedures were the same on both dates. The area was divided into 5 m x 5 m quadrats, and quadrats to be sampled were selected at random. Individual sample location within each quadrat is shown in Fig 2-1.

Samples taken on 2 Sep consisted of 20 trios, 5 from each of 4 areas in a bahiagrass pasture. Two of the areas were heavily damaged by mole crickets, with little bahia grass remaining. The others were relatively undamaged. Each trio consisted of one sample with each method. Thirty samples trios were taken on 16 Sep , 10 from each of 2 areas in a bahiagrass pasture and 10 from an adjacent bermudagrass pasture.

Sampling Arenas

Four sampling arenas were constructed in a bahiagrass field at the University of Florida Horticulture Unit Farm near Gainesville, FL. Each arena enclosed a 10 m x 10 m area within sheet metal barriers. The barriers were 61 cm wide sheet metal buried 40-45 cm in the ground (and extending 15-20 cm above ground level). Scapteriscus vicinus was present but not numerous in the field, and no attempt was made to exclude or include areas of mole cricket activity when laying out the arenas. The arenas were

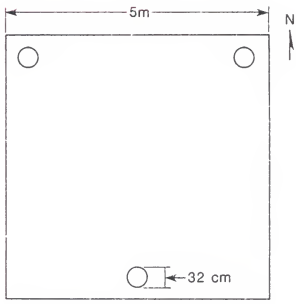

Fig. 2-1. Location of individual samples in 5 m x 5 m quadrat. Core sample was taken at center of southern edge.

adjacent to one another, resulting in a 40 m x 10 m area subdivided into 4 10 m x 10 m squares. Two had linear pitfall traps (4 3-m arms, modified from Lawrence 1982) installed in the center.

On 26 Aug 1984, 500 S. vicinus nymphs were released in each of 3 of the arenas (#2-4). At the same time 20 nymphs were placed individually into 14-liter soil filled plastic buckets with perforated lids. These mole crickets acted as controls for estimation of mortality due to handling, which experience had shown to be important. After 48 hours, 4 of the controls had died. On 12 Sep, 100 vicinus nymphs were added to each of arenas 2-4 (to replace the estimated 20% mortality) and 500 nymphs were added to arena 1, the first release in that arena. The 4 dead nymphs in the control were also replaced. On 21 Sep, 500 nymphs were added to arenas 1 and 3.

Releases were made by sorting pitfall collected nymphs randomly into groups of 100 for introduction into the arenas. These nymphs had been held in the laboratory in soil-filled plastic buckets from the time of capture until release. Holding time for nymphs used in the first release was 1-21 days, with most (> 75%) stored 7 days or less. Storage time for nymphs released on 12 Sep was 6 days or less; those released 21 Sep were captured within 4 days of release. No control crickets from the last group died before the end of the study.

On 15 days between 26 Aug and 29 Sep, 10 soil flush samples were taken in each of 2 or more arenas. The flushing solution (15 ml Joy® liquid in 4 l of water) was poured over a 0.5 m x 0.5 m area, and all crickets surfacing within the area (as delineated by a square of those dimensions made of 1 in. dia. PVC pipe) over the next three minutes were counted. After 16 sets of 10 samples, the time was reduced to 2 minutes since no crickets had been taken in the third minute. This reduced the time range required to sample the arenas, minimizing any differences due to time lag. Location of individual samples was determined at random from the 100 1-m^2 quadrats in each arena, with the samples centered in the selected quadrats. No quadrat was sampled 2 days in succession. Any crickets surfacing were removed and replaced, and crickets surfacing outside the sample square were not counted.

On each sample date, soil samples were taken in each arena at either 2 or 3 (depending on the date) randomly selected locations. The top cm of soil was scraped away and a 7 dram plastic vial forced into the ground, removing a 50 mm long x 27 mm diameter core. This sample was then weighed, dried in a drying oven, and reweighed to determine per cent moisture (by weight). Soil temperatures at 5 cm depth (maximum and minimum for the preceding 24 hrs and current temperature) were also recorded from a buried maximum-minimum thermometer.

The arenas were irrigated to provide a range of soil moisture conditions. Sprinklers delivered ca. 2-3 cm water to arenas 3 and 4 on 13 Sep, and 12-15 cm to all arenas on 26 and again on 27 Sep.

Results

Field Comparison

Analysis of variance of the field sample data showed no statistical difference between the 3 sampling methods on either date under any conditions (F-test, $p=.05$). Nor was there any statistical difference in numbers taken from bahia and bermudagrass pastures (Student's T-test, $p=.05$). There was a significant difference (T-test, $p<.05$) in the numbers taken in damaged vs. undamaged areas, with the sample mean in damaged areas more than twice that in undamaged areas (Tables 2-1 and 2-2).

Sampling Arenas

The total number of S. vicinus present in each arena before release was estimated by comparing numbers sampled in 3 sets of 10 samples each (one set in each of arenas 2-4) taken on 26 Aug with results obtained in subsequent samples under similar conditions. Each of those 3 sets of samples produced one vicinus in 10 flushes. Soil moisture levels averaged 11.9% (SD=1.59). Assuming that flush efficiency is not affected by density in the range involved here, then if x = no. vicinus present before release, c = no. vicinus

Table 2-1. Results of field sampling for mole crickets using 3 methods, 2 Sept. 1982, in a bahiagrass pasture at LaCross, Fla. Method means are not significantly different (F-test, p=.05). Area totals are significantly different (T-test, p=.05).

Area	Methods			Area Total
	Soap	Pyrethrins	Core	
Damaged	21	27	20	68
Undamaged	8	12	10	30
Method total	29	39	30	
Method mean (n=20)	1.5 a	2.0 a	1.5 a	

Table 2-2. Results of field sampling for mole crickets using 3 methods, 16 Sept. 1982, at Hawthorne, Fla. Means are not significantly different (F-test, p=.05).

Area	Methods			Area Total
	Soap	Pyrethrins	Core	
Bahia 1	6	15	7	28
Bahia 2	8	9	5	22
Bermuda	9	12	10	31
Method total	23	36	22	
Method mean (n=30)	.77 a	1.2 a	.73 a	

added (net), N0 = mean of pre-release flushes, and Ni = mean of ith sample set, the equation:

$$x/N0 = (x+c)/Ni$$

when solved for x gives an estimate of the number of crickets present before release.

While the mathematics involved are straightforward, definition of "similar conditions" is not. Variables which were thought likely to have an effect on flush sample results at the outset of the study were soil moisture, soil temperature, and maximum and minimum soil temperature for the previous 24 hrs. Regression analysis with flush mean as dependent variable and soil moisture and the 3 temperatures as independent variables showed only soil moisture to be related to flush mean variability. Therefore, only soil moisture was used as a criterion for defining "similiar conditions".

Of 46 sets of 10 flush samples, 24 were taken when soil moisture measurements were not statistically different (Student's T-test, p=.05) from pre-release levels. Solving the above equation for each of those sets and taking the mean yields an estimate of 153 vicinus in each arena prior to release (St. Err.=27.89).

The net number of crickets added was not the same for each arena, or day to day for a given arena. Of 500 crickets added to arenas 2-4, an estimated 100 died within 48 hrs (before any samples were taken), so C was 400 for the period 28 Aug-12 Sep. Of the 100 added to 2-4 and 500 added

to arena 1 on 12 Sep, an estimated 25 % died within 48 hrs, so C for the period 14 Sep-21 Sep was 475 for arenas 2-4 and 375 for arena 1. No control mortality occurred for those released 21 Sep, so C for the period 21-29 Sep was 875 for arena 1, 975 for arena 3, and 475 for arenas 2 and 4 (Table 2-3).

Calculation of Efficiency

Efficiency of the flushing technique was defined as the estimate of total number of crickets in an arena based on sample data as a fraction of the total known to be present. Each individual sample covered 0.25 m^2, so the estimated total was 40 x total of 10 samples. This was compared to the appropriate estimate of true total (Table 2-3) and efficiency computed.

The data were analyzed using the SAS GLM procedure (Littell and Freund 1982). Efficiency values were transformed by the logistic transformation:

$$\text{transformed efficiency} = \ln [(1-E)/E]$$

where E = efficiency + 0.001 to avoid zeros in the denominator. The resulting values were fitted to a linear model with efficiency (transformed) a function of soil moisture.

Table 2-3. Estimated total S. vicinus present in sampling arenas.

Date	Net # Added (C)	Estimated Original Population	Total Present (T) Arena 1	Arena 2	Arena 3	Arena 4
28 Aug-12 Sep	400	153	-	553	553	553
14 - 21 Sep	475	153	-	628	628	628
	375	153	528	-	-	-
21-29 Sep	475	153	-	628	-	628
	875	153	1028	-	-	-
	975	153	-	-	1128	-

Discussion

Field Comparison

Results of the field comparison were surprising, since it was assumed that the soil corer would provide an absolute sample. Previous work on crickets held in buckets of soil (S.L. Walker 1979, Hudson unpublished data) had demonstrated that soil flushes were highly variable and not very efficient. That the results from the three methods were so similar suggests that the flushing procedure works better in the field than in buckets, or that the soil corer is not as efficient as believed, or both. Walker (1979) speculated that confining mole crickets in buckets affects their behavior, and my observations support this conclusion. Even a relatively large cage seems to have some effect, especially at higher densities. In addition to being confined, the crickets also receive other signals (moving the bucket, removing the lid, striking the sides, etc.) that something unusual is happening. Mole crickets surface because the soap solution is irritating to them, but often will quickly return to the burrow if a threat is detected. Should this threat be apparent before the soap is applied, it is likely that at least some will not surface.

It should be noted that crickets vary in their reaction to the particular soap solution used. No quantitative data are available, but smaller nymphs are immobilized more quickly and suffer greater mortality than larger nymphs and

adults. Small nymphs are paralyzed within a few seconds of exposure, and less than 25% recover from this paralysis. Larger nymphs and adults are extremely irritated by the solution and scramble frantically to get out of it, but some never suffer paralysis and more than 75% of the large (i.e. those with wingpads) nymphs and adults recover within 5-10 minutes, with no lasting ill effects. With the pyrethrin insecticide solution there is the added problem of crickets dying before reaching the surface. Other studies (Ulagaraj 1974, Walker 1979) have found subsurface mortality to be as high as 65% of total mortality for similar insecticides.

Since neither of the flush solutions can be assumed or expected to be 100% efficient, we must suspect that the soil corer is not either. The corer samples an area of such small dia (ca. 32 cm) that many crickets may be able to get out from under it before digging is complete (around 15-30 sec).

While there are no statistically significant differences among the methods, there are substantial differences in expense and convenience. The soil corer is by far the most expensive in terms of equipment and time, and also the most difficult to use, because it requires a tractor and at least 2 people to operate. In addition to the time involved extracting the samples, there is the problem of transporting samples to the lab and time consumed sorting through the soil (but, see Fritz 1983). The method is also destructive of the pasture and most farmers prefer

that the holes be filled in, requiring that buckets of soil be taken to the field.

Soil flushing requires only one person and no equipment except water buckets and a sprinkling can, and so is far simpler and less expensive to use. Of the flushing agents, dishwashing soap is cheaper and more readily available, making it the better choice for field sampling. While Joy® liquid was used in these tests, other studies have shown that several brands are equally effective (Short and Koehler 1979).

These results show that the sampling methods are equally effective, but say nothing about how effective they are. Evaluation of efficiency of the soap flush technique was left to the sampling arena study.

Sampling Arenas

A single estimate of pre-release vicinus population level was used for all arenas, rather than individual estimates in each arena, for several reasons. The area enclosed in the arenas was small and there were no apparent differences in ground cover or mole cricket activity between the 4 arenas, so the assumption of equal populations of vicinus seems valid. Pooling of data provided a larger number of observations to be included in the estimate, an important consideration given the extreme variability of the data. Individual estimates of pre-release numbers ranged from 37 to 475 per arena. Pooling also allowed estimation

of the population in arena 1, where no pre-release samples were taken.

Lack of any statistically significant relationship between flush sample results and soil temperature reflects the relatively small range of observed values. Temperatures during sampling varied from 26.0° to 31.0° C with the range for maximum and minimum temperatures even smaller (32.0° to 35.5° and 19.5° to 22.0° respectively). Analysis of data from longer-term studies shows that there is no correlation between sample results and temperatures for the range of temperatures found in north Florida during the time vicinus nymphs are active (June through October) (see Ch.4).

Logic and field experience suggested that the relationship between efficiency and soil moisture would follow a sigmoid curve, with low efficiency (approaching 0) at low soil moisture and higher efficiency (approaching 100%) at higher soil moistures. Mole crickets are susceptible to desiccation, and spend less time in the upper layers of soil when those layers are relatively dry. Also, the flushing solution does not penetrate very far into dry soil. These factors combine, resulting in fewer mole crickets coming in contact with the flush solution when soil moisture levels are low. Increasing soil moisture increases both penetration by the flush solution and mole cricket activity in the upper layers, so that a higher proportion of crickets present come in contact with the soap. The extreme case is when total saturation is reached and the soil is

flooded, forcing the mole crickets to the surface (Van Zwaluwenburg 1918). This suggests that efficiency would be an increasing function of soil moisture, asymptotic to 0 at low moisture and 100% at saturation levels.

A plot of mean efficiency against soil moisture (Fig. 2-2) indicates that the relationship, at least at low to moderate soil moistures, follows the general shape of a logistic curve. Unfortunately, no data are available for higher (16% and up) moisture levels. The soil in north Florida is very sandy and dries out so quickly that irrigation applied 8-10 hrs per night for 2 nights (12-15 cm water delivered each night) resulted in moisture levels of only 15-16%. Saturation level for these soils is 22-25%.

The logistic transformation of mean efficiency for the lower population density resulted in a highly significant linear regression of efficiency on soil moisture (F-test, $p<.0001$) with an r^2 value of 0.65. A similar treatment of individual sample efficiency values also resulted in a significant regression (F-test, $p<.0001$) but the r^2 value for individual samples is only 0.08 because of the many 0 values in the data.

Similar analysis of the higher density data (i.e. arenas 1 and 3 after 21 Sep, a total of 9 sets of 10 samples) found no significant relationship between efficiency and soil moisture (F-test, $p>0.33$). This is in keeping with the high degree of variability and the relatively few means (9 high density vs 37 low density). A

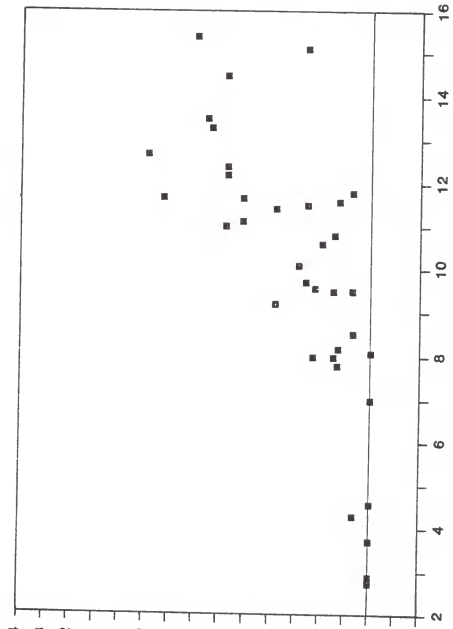

Fig. 2-2. Flush efficiency (based on mean of 10 samples) as a function of soil moisture(% by weight). Population density ca. 5 S. vicinus nymphs/m^2.

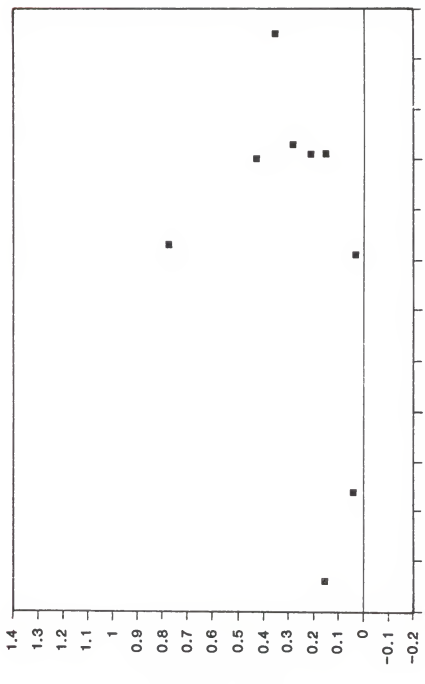

Fig. 2-3. Flush efficiency (based on mean of 10 samples) as a function of soil moisture (% by weight). Population density ca. 11 S. vicinus/m².

plot of mean efficiency vs. soil moisture illustrates this problem (Fig 2-3). There is a trend in the data, however, suggesting that a larger number of samples would reveal that the relationship also follows a logistic curve. When data from both density levels are included in the same model the regression is again highly significant ($p<.0001$) with $r^2=0.55$.

The regression equation for all data is: transformed efficiency = 5.138678 - 0.379155 X % soil moisture. Predicted efficiency (as a decimal fraction) can be calculated from the equation or read from the graph of predicted efficiency vs soil moisture (Fig. 2-4) and used to interpret field sample data if soil moisture is determined at the time of sampling.

Caution should be used when applying these efficiency predictions, especially under conditions of higher (> 17%) soil moisture. The equation is based on data that did not include any observations when soil moisture was above 17%, so behavior of the relationship in the vicinity of the upper limit (approaching 100% efficiency) is untested.

Very similar regression results are obtained using the simple logarithmic transformation of efficiency:

transformed efficency = ln [efficiency + 0.001]

(again adding 0.001 to efficiency to avoid 0 values) as the dependent variable ($r^2=0.57$). This relationship has less intuitive appeal, however, and the regression equation

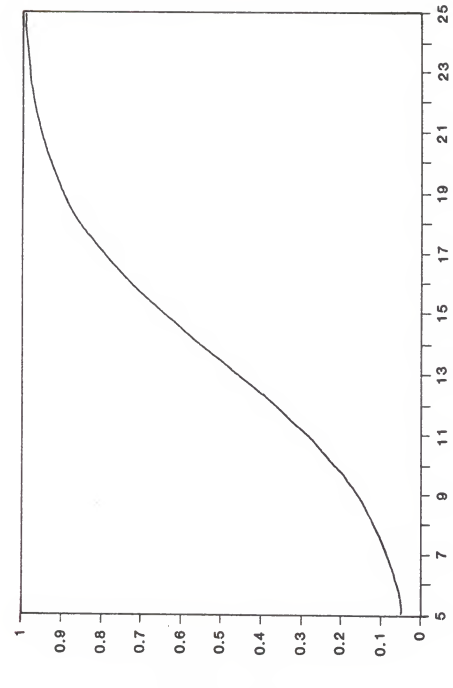

Fig. 2-4. Predicted flush efficiency as a function of soil moisture.

predicts 100% efficiency at 16% soil moisture, a result which is at odds with field observations (Fig. 2-2 and 2-3).

Confidence limits have not been included in Fig. 2-4. The regression equation is based on transformed efficiency values and conversion back to efficiency produces confidence intervals that are asymmetric about the predicted values. They are also very large intervals due to variability of the data. For example, predicted efficiency at 19% soil moisture is 0.88 and 95% confidence interval for a set of 10 samples is (0.36, 0.98). At 10% soil moisture predicted efficiency is 0.20 with 95% C.I. (0.01, 0.74). Obviously, the sampling technique is not very sensitive to population differences unless a very large number of samples are taken.

Of some concern also is the limited range of population densities at which the sampling scheme has been tested. Most (37 of 46) sample sets were conducted on a relatively low density population (ca. 5-6 _vicinus_/m^2). This contrasts with the field situation in which populations exceeding 20 nymphs/m^2 are common. Unfortunately, the experimental design and necessarily large size of arenas precludes working with densities much higher than those used here until some way of managing very large numbers of nymphs is found. Pitfall traps capture large numbers of nymphs on a regular basis, but extensive manpower is needed to operate traps and handle the crickets given their susceptibiltiy to disease if not handled carefully.

The efficiency predictions apply only to nymphs, as adult behavior is markedly different from nymphal behavior. Radioisotope studies (Ch.3) and movement studies using pitfall traps (Ch.4) showed that adults do much less surface tunnelling than nymphs, especially in the fall. Adult females in the fall tend to dig a permanent burrow system and stay there, with little apparent foraging. Males are more active on the surface but not as active as nymphs. They also dig extensive burrow systems (Nickerson et al. 1979). In addition to the apparent greater tolerance of older crickets for the soap solution, adults often have an established and deep burrow system into which they can retreat rather than coming to the surface. Nymphal behavior is not as well studied as adult behavior, but available evidence suggests that they are largely nomadic, with no "home" burrow, and so are more likely to seek escape on the surface.

While there are still unanswered questions about the sampling technique developed here, it represents a significant step forward in the study of mole cricket ecology. Methods outlined here can be used to refine the prediction equation for flush sample efficiency (for instance, by increasing sample size or range of conditions), but meanwhile, for the first time, a means is available for obtaining population estimates of mole crickets in the field.

Sampling Program

Procedure. Standard flushing solution is 15 ml dishwashing soap in 4 liters of water. This solution is poured over an area 0.5 m x 0.5 m and all mole crickets surfacing within 2 min counted. A 0.5 m x 0.5 m square made of 1/2 in PVC pipe works well to delineate the area sampled, and crickets surfacing outside the area should not be counted. Soil moisture can be determined by taking a sample of ca. 30-40 gm of soil in an airtight container (snap cap plastic vial works well) to the laboratory for weighing, drying and reweighing. The sample should be taken from 2-4 cm depth, avoiding the surface layer (top 1-2 cm). This method of measuring soil moisture is simple, almost foolproof, and is not affected by soil type. It does require a good quality balance for weighing the samples (a Mettler model AC100 was used in this study).

Location of samples. Flush sample results typically include many zeros, especially at lower population densities, and statistical manipulations are facilitated by working with means of sets of 10 samples. Location of individual samples is best accomplished by selecting a reference point and using that as the corner of a 10 m x 10 m square grid of 100 1-m^2 quadrats. A random number table can then be used to select 10 quadrats to be sampled. Since the sampled area is only 0.5 m x 0.5 m the sampling of one quadrat will not affect adjacent quadrats. Soil samples

should be taken in at least 2 randomly selected locations in each 10 m square area.

Reference points can be located in a variety of ways (see Southwood 1982 for discussion). Number of sample sets to be taken depends on the size of the area to be sampled, variability of results, and the desired level of precision.

Timing of sampling. Soil flushing is not a reliable method of sampling adult mole crickets, and the procedure outlined here should be used to estimate only the nymphal population. Egg hatch in north Florida begins in May and is essentially complete by July (Forrest 1985). This corresponds to the disappearance of adults, and by 1 Jul the population is composed almost entirely of nymphs. Adults begin to reappear in some numbers in September and by late October are again a majority (Hayslip 1943). Flush sampling, then, is appropriate only from mid-June through September.

The relationship between soil moisture and sample efficiency places a restriction on the use of soil flush sampling. Lower soil moisture leads to lower efficiency and a larger adjustment factor by which one must multiply sample results to obtain population estimates. This in turn inflates the variance, requiring more samples to achieve a given level of precision. (If the expected variance of a function $F(y)$ is $V(y)$, then the expected variance of the function times a constant, $C \times F(y)$, is $C^2 \times V(y)$).

The prediction equation for flush efficiency as a function of soil moisture predicts 50% efficiency at 13.3% soil moisture. It is probably best to restrict sampling to times when soil moisture is at or above this level. This is easily accomplished if irrigation is available, as is the case for golf courses, lawns, and turf farms, but local weather conditions will often dictate the sampling schedule in pastures in the porous sandy soils of Florida.

CHAPTER III
NEAREST NEIGHBOR DISTANCE AS A MEASURE OF SPATIAL DISTRIBUTION OF *Scapteriscus vicinus*

Introduction

The tawny mole cricket, *Scaptericsus vicinus* Scudder, is the most important pest of turf and pasture grasses in the state of Florida. The subterranean lifestyle and great mobility of these insects make ecological and behavioral studies difficult. Direct observation of movement and intraspecific interactions in the field are impossible, and yet information of these types is vital if we are to understand the ecology of mole crickets. Certainly, any sampling technique or program should take into account the spatial dispersion of the insects underground.

Evidence from several sources indicates that mole cricket distribution in the field tends to be clumped rather than random. Damage to pastures appears first as isolated areas of grass loss, although damage may quickly spread. Flush samples from damaged areas produce more crickets than samples from adjacent undamaged areas (Chap. 2). Kleyla and Dodson (1978) found that calling males in a small (60 m x 20 m) field were clumped. Females and non-calling males were not studied. On a smaller scale, damage

studies in 1.5 m diameter field cages planted with grass plugs showed that mole crickets tend to concentrate feeding damage on one or a few plugs rather than feeding equally on all available food (Hudson, unpublished data). If the apparent aggregation is a fact and extends to non-feeding periods, then knowledge of this clumping will be helpful in evaluating sampling data and planning sampling programs.

Materials and Methods

All mole crickets used were adult female S. vicinus collected at sound traps in the vicinity of Gainesville, FL, (cf. Walker 1982) within 48 hours of use. Crickets were placed individually into soil-filled 16-oz plastic cups with perforated lids and held in the laboratory for tagging. Each cricket was fed 1 Grape-Nuts® kernel soaked with a solution of Cs-137 (as described in Hudson and Cromroy 1985). Kernels were dried under a lamp (May 1983) or left damp (October 1983 and May 1984) overnight. The same amount of isotope (ca. 0.05 μCi) was applied to each kernel, and all kernels were approximately the same size, but precise uniformity of dose was not the goal. Activity ranges in counts per minute (CPM) 48 hours after feeding were ca. 15,000 -100,000 CPM in October 1983 and May 1984. Treated crickets were held in the lab for 48 hrs after feeding before release into field cages.

Field cages were 1.5 m diameter x 0.5 m high sheet metal cylinders with screen bottoms and removable screened lids filled with 25-30 cm soil. Four plugs of Pensacola bahiagrass (10 cm diameter) were planted in each cage, one approximately 30 cm each cardinal direction from cage center. Five crickets were released into each cage. One cage was used 17-18 May and 11-13 Oct 1983, and 5 were used 22-23 May 1984.

Beginning 24 hours after release, crickets were located over a 24 hour period using a survey meter with either a NaI crystal scintillation probe (1983) or G-M type radiation probe (1984). Crickets were located at 1-2 hour intervals in May 1983 (total of 13 times). This was reduced to 4 times in 24 hours for October 1983 and May 1984. Locations were recorded as distance from cage center along 2 axes and then plotted on a grid. Distance to nearest neighbor was measured from the plotted points.

Deviation of observed mean nearest neighbor distance from predicted distance assuming random distribution was tested statistically using the methods described by Clark and Evans (1954). In those instances where some crickets were not located, it was assumed that the missing individual was in the tunnel with one of the others (i.e. nearest neighbor distance = 0). When 2 or more individuals were missing, it was assumed that the crickets were paired (rather than in groups of 3 or more).

Expected values for nearest neighbor distance were calculated using the equation:

$$\text{mean distance} = 1/(2\sqrt{p})$$

where p = population density ($p = 2.83/m^2$ or $2.26/m^2$ for 5 or 4 crickets per cage). The standard error of the mean distance to nearest neighbor is given by the equation:

$$SE = 0.26136/\sqrt{(Np)}$$

where N = number of measurements made and p is as before (Clark and Evans 1954).

Results

Mean distance to nearest neighbor was significantly greater than predicted under the assumption of random distribution, for 4 of 5 trials in May 1984 ($p=.05$). Mean distance was significantly less in May 1983, and not different than expected in October 1983 and the 5th trial in May 1984 (Table 3-1). Confidence intervals (95%) based on the standard variate of the normal curve were (0.2494-0.3250 m) in May 1983, (0.2192-0.3552 m) in October 1983 and May 1984 for 5 crickets per cage density, and (0.2475-0.4177 m) for 4 crickets per cage in May 1984.

Discussion

As calculated, these observed distances are conservative since missing individuals were assumed to be paired with located individuals. This assumption produces 2

Table 3-1. Mean distance to nearest neighbor for *S. vicinus* females in field cages.

Date	Cage	Density (vicinus/m)	Observed Distance (m)
May 1983	1	2.83	0.19*
Oct 1983	1	2.83	0.28
May 1984	1	2.83	0.42*
	2	2.83	0.38*
	3	2.83	0.52*
	4	2.26	0.36
	5	2.83	0.58*

* indicates values which are significantly different (p=.05) from expected under hypothesis of random distribution.

distances of 0 for every missing cricket. In those cases where 2 crickets were missing, only 1 actual distance was included in the calculations. Missing crickets were paired with the individuals farthest from the others, thus replacing the largest observed distances with 0's.

In May 1983, 26 of 65 distances included in the mean were 0 (13 missing crickets). This proportion was so high because the crickets were not emitting enough radiation to be detected reliably if they were at the bottom of the cage (i.e. 30 cm deep). Subsequently, the Grape-Nuts® were not dried under a lamp since this apparently evaporated some isotope solution before it could soak into the kernels, leaving cesium on the petri dish. At higher activity levels (75,000-100,000 CPM), missing crickets were less of a problem. All crickets were found each time in October 1983 and at most 2 measurements (out of 16 or 20) were missing in May 1984.

The only instance when an observed mean distance to nearest neighbor agreed with expectations based on previous evidence of aggregation was in May 1983. The high proportion of missing values (and consequent 0 distances) in the data make the results suspect in this case. Of the other 5 spring trials, 4 resulted in mean distances which led to rejection of the random distribution hypothesis, with values which indicated a tendency toward uniform distribution (observed distance significantly greater than expected). The other spring trial (cage 4 in May 1984) used

only 4 crickets (density of 2.26 vicinus/m^2) because the 5th was found dead on the surface within 24 hours of release.

These results suggest that vicinus females do not aggregate, even for feeding, and in fact may be actively avoiding one another in the spring. The October 1983 results agree with observations of adult vicinus behavior, both in cages and in the field, and support the idea that there is a seasonal change in behavior.

It should be noted that temperatures in north Florida are similar in May and October. Maximum and minimum temperatures, measured 4-5 cm below soil surface in a pasture near Gainesville, were 30° and 22° C, respectively, on 13 Oct 1983. On 10 May 1984 in the same pasture, temperatures were 30° and 17° C. These ranges are typical of the weather in the area during May and October, and temperature effects have been discounted in explaining seasonal differences.

Although some vicinus females fly in the fall and are attracted by calling males, there is little mating and no eggs are laid until spring (Walker and Nation 1982). Most fall adults are apparently waiting for spring and the reproductive season. Surface movement, as measured by pitfall trap captures in areas of high population density (Chap. 4), is at a minimum compared to nymphs or spring adults. This is even more true of females than males, and crickets captured in pitfalls in the fall and winter are usually almost 100% male. Apparently females in the fall fly

if they move, and when not flying they do what those in the study did -- dig a "home base" burrow and stay there, making only short surface tunnels around the main burrow for foraging.

Adults in spring, however, have very different priorities. Flight activity for dispersal and/or mate finding peaks in March with a peak in egg laying in May (Forrest 1985). Females may be able to reduce competition for their own offspring by providing as much distance as possible from other egg clutches in a given area. This would explain the tendency toward overdispersion observed in May 1984, but the means by which mole crickets underground detect the presence of others not in the same tunnel is unknown.

Also left unexplained is the concentration of feeding damage observed so often in cage studies. Laboratory feeding studies have shown that adult vicinus do not feed every day (Kepner 1985), so the effective density at grass plugs may be lower than it seems. The higher densities used in damage studies (10 adults per cage vs 5 in tagging studies) may affect distribution and movement of adults, as has been seen with nymphs (Chap. 4).

Conclusions

While mole cricket populations may appear to be clumped when observed on a large scale (i.e. in a pasture), females

in outdoor cages showed no tendency toward aggregation. In May females tended to be distributed more uniformly than random at the densities used (ca. 3 vicinus females/m^2). In October females were randomly distributed and apparently spent most of the time in established "home" burrows.

CHAPTER IV
SURFACE AND SUBSURFACE MOVEMENT OF *Scapteriscus vicinus* NYMPHS

Introduction

The tawny mole cricket, *Scapteriscus vicinus* Scudder, is a highly mobile, largely subterranean insect native to South America. It was introduced into the United States around 1900 (Walker and Nickle 1981) and is now found throughout the coastal plains of the southeastern states, where it is an important pest of turf and pasture grasses. The spectacular dispersal flights of this insect have contributed greatly to its rapid spread in the region and also to its pest status, as infestation or reinfestation of mole cricket free areas can occur each season. Several studies have been made of *S. vicinus* flight behavior (Ulagaraj 1975, Ulagaraj and Walker 1975, Forrest 1983, Matheny et al. 1983, Walker et al. 1983, Walker and Fritz 1983) and much is now known about this aspect of mole cricket dispersal.

Flights occur during the spring (February - May) and, to a much smaller extent, fall. However, only adults fly, and little is known about movement of non-flying adults or nymphs. Tsedeke (1979) placed radioactive tags on adult *vicinus* and traced their movements in small soil-filled

cages. Movement of radioisotope tagged female vicinus in field cages was reported in Chap. 3. No studies of underground movement of uncaged adults or nymphs have been reported.

Direct observation of individuals as they tunnel about beneath the surface is, of course, impossible, and yet knowledge of this aspect of their behavior is important to the understanding of mole cricket ecology. Surface and subsurface movement allows nymphs to exploit new food sources and to escape areas of high density and depleted food supplies. Migration may allow reinfestation of treated fields from adjacent untreated areas (Poe 1976).

This study investigated factors affecting surface and subsurface movement of S. vicinus nymphs in the field. Experimental arenas were used to study effects of population density and ground cover/food supply, and the diel patterns of nymphal movement. Pitfall traps (modified from Lawrence 1982) were used to monitor activity levels in pastures over extended periods and under a wide range of climatic conditions.

Materials and Methods

Field Traps

Two linear pitfall traps, one with 3-m arms and one with 6-m arms (Fig. 4-1) were installed ca. 50 m apart in a

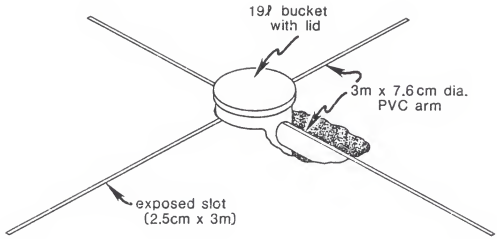

Fig. 4-1. Linear pitfall trap for sampling mole crickets.

heavily damaged bahiagrass pasture (Field 1) near Grove Park, FL., in August 1983. Trap catch was monitored from 6 Sep 1983 through 7 Sep 1984. Two additional pitfall traps (both with 3-m arms) were installed in an adjacent bahiagrass pasture (Field 2) in similar arrangement on 2 Aug 1984 and monitored from 3 Aug through 9 Oct 1984. On each sample date the number and life stage (nymph or adult) of vicinus caught in each trap over a 24-hour period were recorded.

Periodically (approximately weekly when nymphs were active, less often from December through June) during the sample period, 10 soap flush samples were taken in the immediate vicinity of each pitfall trap. Flush sample procedure was to pour 4 l of solution (15 ml Joy® liquid in 4 l water) over a 0.5 m x 0.5 m area and record the number of mole crickets surfacing in the area over a 3 min interval beginning when the flush solution was completely applied. Sample locations were selected at random from the 400 1-m^2 quadrats in a 20 m x 20 m grid centered about each pitfall trap. Trap arms marked the cardinal points, and a random number table was used to select quadrant and quadrat to be sampled.

Maximum and minimum temperatures for the preceding 24 hours, along with current temperature, were measured at each sampling date by a maximum-minimum thermometer buried 5 cm in the soil midway between the 2 traps in Field 1. Soil moisture was measured by taking soil samples (5 at first,

later reduced to 3) from randomly selected quadrats around each trap. Each sample consisted of a 27 mm diameter x 50 mm long core of soil obtained by scraping away the top cm of soil and forcing a plastic vial of those dimensions into the ground. The core was taken to the laboratory and weighed, dried in an oven, and reweighed to determine the soil moisture level (% by weight).

Malathion bait was applied for mole cricket control in Field 1 on 3 Aug 1984 and in Field 2 on 28 Aug 1984.

Experimental Arenas

Eight pitfall arenas were constructed at the University of Florida Horticulture Unit Farm near Gainesville, FL. Each arena was a 3 m x 3 m plot bounded by linear pitfall traps (modified from Lawrence 1982). A sheet metal barrier 30 cm deep was placed under each pitfall to prevent nymphs from escaping the arena without falling into the trap (Fig. 4-2). The arenas were set up in 2 sets of 4. Two arenas of each set had a mixture of bahiagrass and native weeds as ground cover. The other 2 were bare.

Marked S. vicinus nymphs were released into the pitfall arenas on 3 occasions. Nymphs reared in outdoor cages were used for the first release (25 Aug 1983); nymphs for subsequent releases were captured in pitfall traps in vicinus infested pastures in the Gainesville area. Crickets were marked by placing a single spot of Tech-Pen® ink on the pronotum to identify the arena of release.

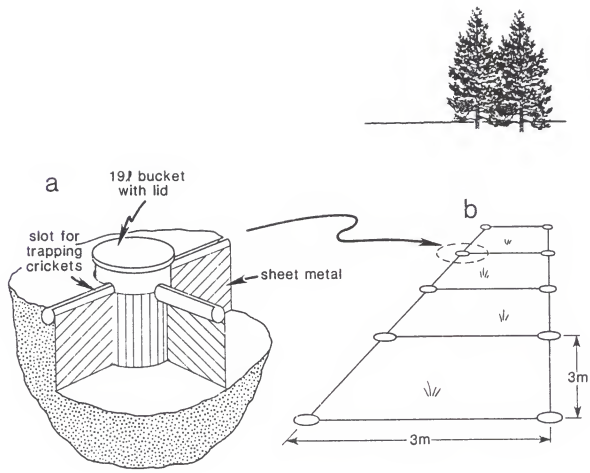

Fig. 4-2. Pitfall arena layout. a. detail of trap construction
b. set of 4 arenas.

On 25 Aug 1983, 44 marked nymphs were released into each of 2 arenas, one bare and the other grass covered. Traps were monitored 3 times daily (8:00 AM, 8:00 PM and midnight) for the next 8 days (26 Aug-2 Sep) with number of each group captured during each interval recorded. On 26 Oct 1983, 45 marked nymphs were released into each of 4 arenas, 2 bare and 2 grassy. Traps were monitored twice daily (7:00 AM and sunset) for 7 days (26 Oct-1 Nov).

On 22 Aug 1984, marked nymphs were again released into 4 arenas. Two were designated "low density" (40 and 43 nymphs released) and 2 were "high density" (79 and 84 nymphs released). Each density group included 1 bare and 1 grassy arena. Traps were monitored 4 times daily for 8 days (22-29 Aug).

Two sampling arenas were also constructed in the same area. These consisted of 10 m x 10 m plots bounded by sheet metal barriers 40-45 cm deep and extending 15-20 cm above ground. A linear pitfall trap with 4 3-m arms was centered in each arena. These sampling arenas were used to study effects of population density, soil moisture, and rainfall on nymphal movement. On 26 Aug 1984, 500 pitfall collected S. vicinus nymphs were released into each arena. On 12 Sep, 100 nymphs were added to each arena, and on 21 Sep, 500 were added to one arena (but not the other). Traps were emptied daily or every other day from installation until 4 Oct (total of 26 days when traps were checked after cricket release on 26 Aug).

Ten soap-flush samples were taken in each arena on 26 Aug (prior to release), along with a soil sample from each arena. Results from these samples were compared to results from later samples to provide an estimate of pre-release population levels. Sampling procedure was as before, and a random number table was used to select the 10 quadrats to be sampled (see Ch. 2). Soil samples were also taken in each arena at each sampling date. Maximum and minimum soil temperature for the preceding 24 hours, along with current soil temperature, were read from a maximum-minimum thermometer buried 5 cm in the soil beside the arenas.

Irrigation water was applied to the arenas by sprinkling to provide a range of soil moisture conditions. Approximately 7 cm water was applied on 13 Sep, and 12-15 cm on 24 and again on 26 Sep.

Results

Field Traps

There was a strong correlation between pronotal length and activity as measured by the ratio of pitfall captures to population density (r=0.932, Fig.4-3). For nymphs of similar size, there was a significant difference in numbers captured in pitfall traps between populations of 5-10 nymphs/m^2 (mean=5.2 nymphs per 24 hours, SD=6.05, n=48)and 15-16/m^2 (mean=152 per 24 hours, SD=72.12, n=30) (T-test, p=.05). There was little correlation between mole cricket

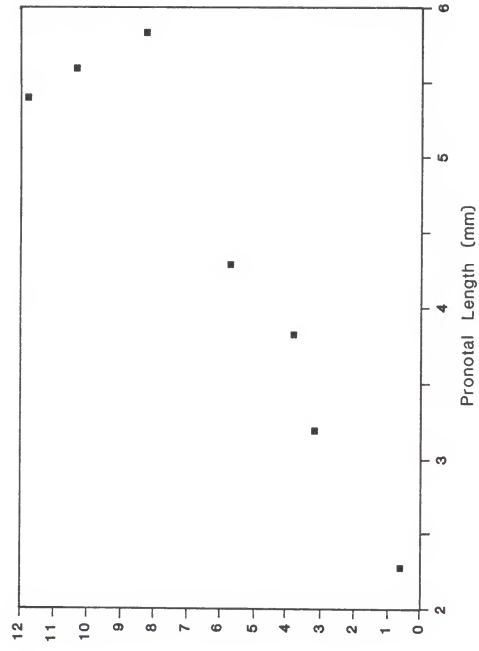

Fig. 4-3. Relationship between activity index (mean pitfall capture/ population density) and size of S. vicinus nymphs.

activity and temperature or soil moisture over the period of May through October (correlation coefficients were r=0.15 and r=0.17 respectively).

Pitfall capture records for the period September 1983 through August 1984 indicate that pitfall catches drop in fall as the weather cools and adults begin to appear. No mole crickets were captured from December through April (Fig. 4-4).

Experimental Arenas

Ground cover had no effect on rate of nymphal movement out of the pitfall arenas in any of the trials. Population density seemed to affect the rate of movement, as pitfalls captured almost twice the percentage of nymphs from higher density arenas as from lower density arenas (Table 4-1), but this difference was not statistically significant (Fisher's exact test, $p>.10$). There were seasonal differences in the diel pattern of activity (Table 4-2). Most activity in the summer occurs at night (77% and 63% of captures in 1983 and 1984, respectively) with early night (sunset-midnight) accounting for about two-thirds of total night captures in both years. In late October the situation was reversed and most captures (76%) occurred during the day. These seasonal differences are statistically significant (Chi-square, $p<.001$)

Sampling arena results are somewhat different from the pitfall arena results in that increasing the population in one arena from ca. 650 to ca. 1100 produced no significant

Table 4-1. Captures of marked S. vicinus nymphs in pitfall areas, 22-29 Aug. 1984. Population densities $5/m^2$ or $10/m^2$.

Time Period	Number Captured (% of Captures) Low Density	High Density
Day		
morning	2 (28%)	3 (12%)
afternoon	2 (28%)	5 (20%)
Night		
early night	2 (28%)	11 (44%)
late night	1 (14%)	6 (24%)
Total Recaptured	7 (100%)	25 (100%)
% of Population	8.4%	15.3%

Table 4-2. Diel pattern of pitfall captures of S. vicinus nymphs.

Time Period	Number Captured (% of Total) Aug 1983	Oct 1983	Aug 1984
Day (sunrise-sunset)	8 (23%)	16 (76%)	12 (37%)
Night	27 (77%)	5 (24%)*	20 (63%)
early (sunset-midnight)	16 (46%)	-	13 (41%)
Late (midnight-sunrise)	11(31%)	-	7 (22%)

*Traps emptied only twice daily in Oct. 1983.

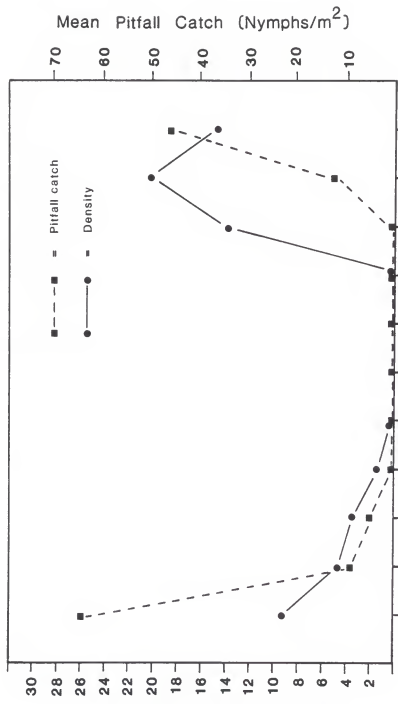

Fig. 4-4. Seasonal trends of pitfall catch and population density of S. vicinus nymphs.

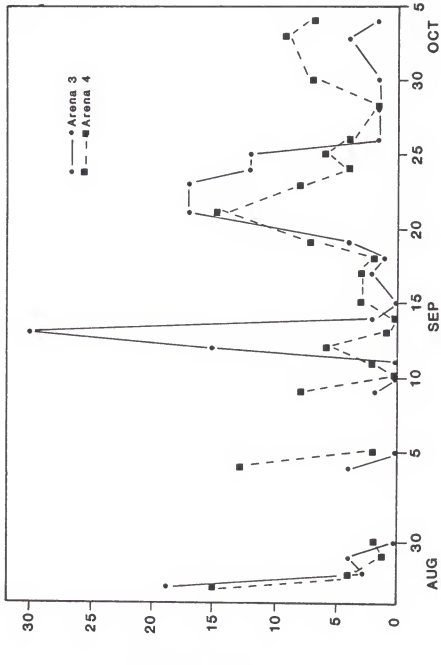

Fig. 4-5. Mean 24 hr pitfall captures of S. vicinus nymphs in two sampling arenas. Initial density ca. 5 nymphs/m^2 in both arenas. Density in arena 3 increased to ca. 11 nymphs/m^2 on 21 Sep.

difference in numbers captured (Fig 4-5). An estimated 153 vicinus (see CH. 2) were present in each arena prior to adding nymphs on 26 Aug, yet none were captured in the pitfalls during the 10 days between installation and release (Table 4-3).

Temperatures were remarkably constant during the study, ranging from 32.0° to 35.5° C maximum and 19.5° to 22.0° minimum. This small range of variation was not correlated with pitfall captures. Nor was there any correlation between pitfall captures and soil moisture, which ranged form 9.5% to 15.1%.

Discussion

Several points had to be considered in interpreting results of this study, especially in the field trap data. Analysis of effects of temperature and soil moisture on nymphal activity had to be restricted to the period of June through September because adults begin to appear in late September in north Florida. Adults apparently do little surface tunneling and so are less likely to be captured in pitfall traps. This is particularly true of females (Ch. 3); fall pitfall catches of adults were 62% male in 1983 and 79% male in 1984. Adults also construct extensive, permanent burrows for overwintering and/or calling, giving them a ready alternative to surfacing to escape the soap flush solution.

Table 4-3. Mean 24-hr pitfall trap capture of S. vicinus nymphs at 3 population densities in pitfall areas.

Estimated Density (nymphs/m^2)	Mean Pitfall Capture (nymphs/24 hrs)
1.5	0
5.0 - 6.5	4.7 (SD=5.47, n=39)
11.0	7.8 (SD=6.65, n=9)

Adults, then, are underrepresented in both pitfall catches and flush samples compared to their proportion in the population, which approaches 75% by December (Hayslip 1943). These methods are not appropriate for measuring mole cricket populations when adults are present. No other method is available which might solve the problems encountered here, so analysis of the data was restricted to the time when adults were not numerous.

Restricting analysis to June through September also restricts the range of temperatures encountered. There probably is a relationship between temperature and mole cricket activity, since nymphs are present almost year round but none are taken in pitfalls in the winter months. These results and field observations suggest that there is a threshold temperature below which there is no surface movement, although reduced activity may also be a response to photoperiod changes.

Soil moisture around the field traps ranged from 10.0% to 20.8% during the study. Saturated soil (i.e. water standing in much of the field) contains 23-25% moisture. Moisture levels below 10% occurred only twice in the year of record, and moisture was always more than 9%. This range of variation in soil moisture had little effect on mole cricket activity (correlation coefficient r=0.17).

Moisture levels in the sampling arenas covered a different range, from 3.7% (very dry) to 15.1% (fairly moist), but so few crickets were captured under any

conditions that any effects of moisture were masked. This was disappointing since it seems certain that there is some relationship between soil moisture and surface activity (Wolcott 1938, Worsham and Reed 1912).

No increase in surface movement, as measured by pitfall captures, was noted in increasing population density from 5 to 11 nymphs/m^2 (Fig. 4-5). Pitfall arena results suggested that little movement occurs, even in bare ground, when density is less than about 3/m^2. Sampling arena results support this, as no nymphs were captured out of the pre-release population of ca. 1.5/m^2. Application of malathion bait to Field 1 on 4 Aug reduced the population to an estimated 1.5 nymphs/m^2, and reduced pitfall captures to at most 2 nymphs in a 24 hour period (mean < 1).

There was a marked difference in surface movement between population densities of 5-11/m^2 in the sampling arenas and 15-16/m^2 in Field 2. Nymphs used in the sampling arenas were taken from pitfalls in late August and were similar in size to the nymphs in Field 2 (some, in fact, were taken from Field 2). Mean pitfall capture in the sampling arenas was 5.2 per 24 hours (SD=6.05, n=48). Mean capture in Field 2 was more than 20 times as many (152 per 24 hours, SD=72.12, n=30).

The ratio of pitfall captures to population density provides an index of activity that is adjusted for density. The strong correlation between this index and size (Fig. 4-3) indicates that larger nymphs move more and farther

than smaller nymphs and are more likely to be caught in pitfall traps. This must be considered if these traps are used to monitor mole cricket populations.

The effects of rainfall on nymphal movement varied from no apparent effect to a marked increase in activity depending on circumstances. After an extended period of dry weather (soil moisture down to 10-11% or less) even a brief shower induced a flurry of activity. No such effect was noted when conditions were moist.

The large number of nymphs captured in field traps day after day was unexpected. The highest population estimate from flush samples (adjusted for soil moisture by methods of CH. 2) in the vicinity of Trap 1, Field 1 was 30.2 vicinus /m^2 on 3 Jul 1984, or about 1570 nymphs within 1 m of the arms of the trap (Trap 1 had 6-m arms). An average of 143.5 nymphs per day was taken from the trap over the period of 8 Jun-3 Aug (n=11 sample days) for an estimated total of 8036 crickets captured (catches were recorded only over 24 hour periods and numbers taken between sample dates were not recorded). This is more than 2/3 of the estimated total of 12,080 nymphs present in the 20 m x 20 m area around the pitfall on 3 Jul but no reduction in pitfall catch over that time was noted. The mean catch per day for the period 20-30 Jul was 164 nymphs (n=5 days, range 46-370). Flush sample estimates dropped from 30.2 nymphs/m^2 on 3 Jul to 15.6 nymphs/m^2 on 13 Jul, but no further decline was noted until 4 Aug.

Similar results were observed in Field 2 from 3 to 25 Aug. A mean of 152.2 nymphs were taken from each trap each day for an estimated total of 3500 nymphs removed from the vicinity of each trap. Population density around the traps during the period was estimated at 15.5 nymphs/m^2 (SD=4.87, n=6 sets of 10 flush samples), or 6080 nymphs in the 20 m x 20 m area around each trap. Again, there was no decrease in either trap catch or flush sample mean over the period, despite the loss of over 50% of the total number estimated to have been in the area at any one time.

These results suggest that vicinus nymphs at population densities of ca. 15/m^2 or more move almost constantly. How far an individual moves is not known. Because of this movement, nymphal distribution within an area should tend towards uniform and away from clumped.

Conclusions

1. Ground cover had no effect on movement out of the pitfall arenas.

2. Increasing population density had little effect on pitfall captures up to ca. 10 vicinus nymphs/m^2 (but populations below 2-3/m^2 were virtually undetectable by pitfall traps). The difference in numbers captured between population densities of 1l/m^2 and 15/m^2 was more than 20-fold (5.2 vs 152 per 24 hours).

3. Soil moisture in the range of 10-20% had no effect on mole cricket movement in the field. Increased activity following rainfall was noted if the soil had been dry (< ca. 12% soil moisture) but not if the soil was already moist.

4. Tawny mole cricket nymphs at higher densities (15/m^2 or more) are apparently nomadic, and probably tend to disperse away from areas of local population peaks.

5. Larger nymphs move more on the surface and so are more readily caught in pitfall traps than smaller nymphs.

CHAPTER V
MOLE CRICKET DAMAGE TO *Hemarthria altissima*:
RESISTANCE OR NON-PREFERENCE?

Introduction

Mole crickets in the genus *Scapteriscus* cause tremendous damage to Florida's pastures and turf grass every year. Estimates of the annual costs to Floridians, in damage and control efforts, exceed 30 million dollars (Walker 1985). The two species most often implicated in the damage, *S. vicinus* and *S. acletus*, were both introduced into the southeastern United States around 1900 (Walker and Nickel 1981). They now occur throughout Florida, and have expanded their ranges to include most of the southeastern coastal plain from the Carolinas around to Mississippi (*vicinus*) and eastern Texas (*acletus*).

Recent studies have shown that the two species have very different feeding habits. Matheny (1981) examined gut contents and found that *acletus* is largely carnivorous, while *vicinus* is mostly vegetarian. This implies that most damage to established pastures and turf grass is caused by *vicinus* feeding, although mechanical damage may result from the burrowing of either species, especially in newly planted stands. Walker and Ngo (1982) found this to be the case

with two pasture grasses, Pensacola bahiagrass (Paspalum notatum) and coastal bermudagrass (Cynodon dactylon).

Chemical control of mole crickets is often ineffective and generally too expensive for use in pastures (Short and Koehler 1979), and the dispersal ability of these pests is such that reinfestation of treated fields may occur each year (Walker and Fritz 1983). Other methods of controlling mole cricket damage are needed to provide turf and pasture managers with long term, inexpensive alternatives to chemical control.

One such alternative is the planting of grass varieties that are resistant to or tolerant of mole cricket damage. Some screening of turf grass varieties has been done (Reinert and Short 1980, Reinert and Busey 1985), but no work on resistance in pasture grasses has been reported. This study investigated mole cricket preference for pasture grasses and screened several varieties of a relatively new introduction, Hemarthria altissima, for possible resistance to damage by these pests.

Materials and Methods

All preference and damage studies were conducted in large cages set up outdoors in a field at Archer Road Entomology Laboratory on the University of Florida campus at Gainesville, FL. Cages were 1.5 m dia x 0.5 m high sheet metal cylinders with screen bottoms and removable screen

lids filled with 25-30 cm of sandy soil. Prior to planting or introduction of mole crickets, the cages were fumigated with methyl bromide to kill any insects already in the soil and approximately 4 oz. of general purpose fertilizer (8-8-8) were added to each cage.

In the preference trials, one 10-cm dia plug of each of 6 grass types -- Pensacola and Argentina bahiagrass and Hemarthria varieties "big alta", "floralta", "green alta", and "red alta" -- was planted in each of 12 cages. Plugs were planted in a circular pattern designed to maximize distance between plugs and from plug to side of cage. Assignment of a particular grass type to its position in a cage was made at random, except that each type occupied a given position in only 2 cages. In the damage study, each of 12 cages was planted with 4 10-cm dia plugs of Hemarthria var "floralta" in a square pattern with ca. 35-40 cm between plugs. All plugs in all cages were planted on 5 Aug 1982 and trimmed to a height of 2-3 cm on 9 Aug.

Cages in both studies were assigned at random to one of 3 treatments -- vicinus, acletus, or control. Each treatment was replicated 4 times in each study. On 11 Aug those cages designated as vicinus received 20 S. vicinus nymphs 10-25 mm in length and those designated as acletus received 20 S. acletus nymphs 5-15 mm in length. Controls were left cricket free.

The grass in all cages was clipped again on 23 Sep and the clippings dried and weighed. The resulting data were

analyzed by analysis of variance procedures and the means separated by Fisher's protected LSD test.

The damage study was continued in the spring of 1983 when 18 cages were used to set up 6 replications of each treatment using adult mole crickets collected at sound traps in the Gainesville area. Cages were again planted with 4 10-cm plugs of floralta and the grass clipped to 2-3 cm before release of 20 crickets per cage on 9 May 1983. Grass was clipped again on 9 Jun and the clippings dried and weighed. Statistical analysis was as in 1982.

Results

Analysis of variance of mean forage production of the 6 grasses showed significant differences among means for both control and vicinus infested groups (F-test, p=.05). There were no significant differences among the grasses in the acletus group (Table 5-1). Comparison of treatment means with control means by grass type using Student's T-test found acletus caused significant (p=.05) reduction of forage production only in green alta. Vicinus caused a significant reduction in forage production by every grass when compared with controls and with acletus groups as well.

Analysis of variance of mean forage weights for floralta showed no significant differences among treatments when nymphs were used (Table 5-2). When adults were released into the cages there were significant differences

Table 5-1. Mean forage production (gm) by six pasture grasses infested with mole cricket nymphs. Means in the same column followed by same letter are not siginificantly different (p=.05, Fisher's protected LSD).

Grass Type	Treatment			% Reduction	
	Control	vicinus	acletus	C vs V	C vs A
Bahia					
Pensacola	12.5 c	0.7 b	9.4 a	94**	25
Argentina	23.6 bc	0.2 b	21.7 a	99**	8
Hemarthria					
Red Alta	31.2 abc	5.1 ab	27.5 a	84*	12
Green Alta	38.3 abc	1.6 b	23.8 a	96**	38*
Big Alta	49.2 ab	7.2 ab	31.4 a	85**	36
Floralta	58.3 a	11.4 a	36.0 a	80*	31

*Reduction is statistically significant (T-test, p=.05).
**Reduction is highly significant (T-test, p=.01).

Table 5-2. Mean forage production (gm) of Hemarthria var. Floralta infested with mole cricket nymphs. (Differences in means are not significant.)

Treatment	Mean	% Reduction
Control	88.9 (SD=47.6)	--
acletus	73.2 (SD=40.5)	18%
vicinus	19.7 (SD=8.2)	78%

Table 5-3. Mean forage production (gm) of Hemarthria var. Floralta infested with mole cricket adults. Means followed by the same letter are not significantly different (LSD, p=.05).

Treatment	Mean	% Reduction
Control	152.9 a	--
acletus	83.7 b	45%
vicinus	13.2 c	91%

between means for all treatments including control vs. vicinus (p=.01), control vs. acletus (p=.05), and acletus vs. vicinus (p=.05). The vicinus mean was less than 10% of the mean for control cages, and only 16% of the acletus mean (Table 5-3).

Discussion

Ranking of means in the preference study shows that the presence of mole crickets had little effect on the relative amount of forage produced by the grasses studied. Loss of stand was severe for the 2 bahia varieties when infested with vicinus, as each had 3 of 4 plugs completely destroyed (Argentine bahia almost lost the fourth). Red alta suffered 25% loss of stand (1 of 4 plugs) to vicinus. No other grass suffered any loss of stand to vicinus. No other treatment produced any loss of stand for any grass variety.

Damage to floralta by vicinus nymphs was severe, but no statistically significant differences could be detected because of extreme variation in forage production in control cages. Six replications (rather than 4) were used in the adult damage study (1983) to overcome this problem. Damage by acletus was less severe than for vicinus, and all plugs were alive and growing at the conclusion of the test. During the same time the vicinus cages suffered 50-100% loss of stand.

Results of the damage study indicate that the apparent difference in damage in the preference study (especially as measured by loss of stand) was mostly a matter of timing, and due to preference rather than any resistance or tolerance by the Hemarthria varieties. Mole crickets are likely to cause just as much damage to floralta pastures as they have to bahiagrass pastures, since when faced with no choice they caused forage reduction and loss of stand comparable to that experienced in damage studies with bahia and bermuda grasses (Walker and Ngo 1982). Mole crickets seemed to prefer the less coarse varieties of Hemarthria and the coarsest two types, floralta and big alta, were the least attacked when other types were present.

CHAPTER VI
EFFECTS OF FOOD TYPE ON GROWTH AND SURVIVAL OF *Scapteriscus vicinus*

Introduction

The tawny mole cricket, *Scapteriscus vicinus* Scudder, is an introduced herbivore that feeds on a wide variety of plants. Its principal economic importance today is as a pest of turf and pasture grasses in Florida and other southeastern states, but it has also been reported to feed on many different vegetable and field crops, and on some ornamentals (Hayslip 1943). Preference of *S. vicinus* for certain varieties of turf (Reinert and Short 1980, Reinert and Busey 1985) and pasture (Matheny et al. 1981, Walker and Ngo 1982, Ch.5) grasses has been demonstrated, but the possible significance of these preferences, in the form of differential growth rate or survival of the mole crickets, has not been studied (although Ulagaraj (1975) speculated that food type might be important to developing nymphs). The effects of food type on *vicinus* growth and survival were studied in 1983 and 1984. Pensacola bahia (*Paspalum notatum*), coastal bermuda (*Cynodon dactylon*), and *Hemarthria altissima* var. `floralta' were offered as food in 1983. In 1984, bahiagrass, bermudagrass, and floralta were tested,

along with two common weeds, carpetgrass (Axonopus affinis) and globe sedge (Cyperus globulosus), and an unfed control.

Materials and Methods

In both years tests were conducted outdoors in 14-liter plastic buckets with screened lids filled with ca. 30 cm sandy soil. A single 10-cm dia plug of the appropriate grass was planted in the center of each bucket (except controls).

Each treatment was replicated 3 times in 1983, and 4 times in 1984. Five newly hatched vicinus nymphs were released into each bucket. The nymphs had never fed and were hatched from eggs laid in the laboratory by females collected at sound traps in the Gainesville area. In 1983, nymphs were placed in the buckets on 31 May and removed 20 Jun. The 1984 test ran from 13 Jul through 17 Oct. At the conclusion of each test the nymphs were removed, weighed, and pronotal length measured. Data were analyzed by analysis of variance to test for differences among treatments, and means were separated by Fisher's protected LSD test.

Results

In 1983 there were significant differences among grass types in both nymphal weight and pronotal length (F-test,

p=.05). Nymphs fed bahiagrass were significantly larger than those fed floralta, and heavier than either the bermuda or floralta groups. There was also a significant difference in weight between bermudagrass and floralta nymphs (LSD, p=.05) (Table 6-1).

Results in 1984 were not so clear cut. Analysis of variance F-test was not significant for either weight or pronotal length (p=.05). Test of the hypothesis of equal survival among treatments (Chi Square Test) also was not significant (Table 6-2).

There were significant differences in mean mole cricket biomass produced by the treatments. Biomass was defined as the total weight of nymphs produced by a replicate of a given treatment, and mean values for the six treatments are listed in Table 6-2. All three pasture grass means were significantly greater than the control mean. The floralta mean was significantly greater than the unfed control, bermudagrass, and the two weeds. The bahiagrass mean was significantly greater than both of the weeds and the control. The bermudagrass mean was not statistically different from either of the weeds, but was greater than the control. The weed-fed nymphs were not different from the unfed controls.

Table 6-1. Mean size and weight of S. vicinus nymphs fed on three pasture grasses, 31 May-20 June 1983. Means in the same column followed by the same letter are not significantly different (Fisher's protected LSD, p=.05).

Grass	Mean PNL (mm)	Mean Wt (mg)
Bahia	4.6 a	145 a
Bermuda	4.2 ab	105 b
Floralta	2.9 b	35 c

Table 6-2. Survival, and mean size, weight, and biomass of S. vicinus nymphs fed on 5 food plants, 13 July-17 October 1984. Means in the same column followed by the same letter are not significantly different (Fisher's protected LSD, p=.05)

Food	Survival	PNL (mm)	Wt. (mg)	Biomass (mg)
Floralta	7/20	5.0a	169a	300a
Bahia	9/20	4.1a	98a	220ab
Bermuda	5/20	4.7a	152a	18bc
Carpetgrass	4/20	4.1a	95a	95cd
Globe sedge	4/20	4.4a	93a	90cd
Control	2/20	4.4a	100a	50d

Discussion

Results from the short-term (21 day duration) study in 1983 agree with results from preference studies where bahiagrass was preferred over bermudagrass (Matheny et al. 1981) and floralta (CH.5). The larger size and weight of bahia-fed nymphs seemed to indicate that bahia-grass was not only the preferred food but a "better" food.

The expanded study conducted in 1984 failed to confirm this. Although more bahia nymphs survived, especially compared to controls (9 out of 20 vs 2 out of 20), the rest of the treatments were scattered in between these two extremes. There was no statistical difference among treatments in mean weight or pronotal length (F-test, $p=.05$). Biomass production by bahiagrass treatments was greater than bermudagrass but not floralta. Bermudagrass biomass was not statistically different from the two weeds, but was significantly less than floralta (LSD, $p=.05$).

When given a choice of several grasses or several varieties of a single species, mole crickets tend to feed preferentially on the finer textured varieties first (Reinert and Short 1981, CH.5). It seems probable that texture alone is the basis for observed preferences, and texture may also explain the differences between 1983 and 1984 results. The 1983 study covered only the first 21 days of nymphal development. Nymphs the following year were left in the buckets for 96 days and so were considerably older

(if not larger). One explanation for the results is that small nymphs have difficulty feeding on the coarser floralta (and, to a lesser degree, bermudagrass) than on the relatively fine textured bahiagrass, and so grow slower initially. This might create a size difference at 3 weeks of age which would disappear once the nymphs attain sufficient size and can feed more easily on the tougher grasses.

This does not explain, however, why the 2 surviving control treatment nymphs were as large as those given an abundant supply of bahia grass. Possible food sources are fellow nymphs (only 1 nymph survived in each of 2 control buckets), algae, and other soil organisms, but no grass or weeds were available.

CHAPTER VII
SUMMARY

Elucidating the relationship between soil moisture and flush sample results is an important step in the development of a sampling program for mole crickets since it explains much of the variation observed in previous work with the technique. The equation predicting efficiency at any soil moisture level provides, for the first time, a means of relating sample results to actual population numbers so that an estimate of population density can be obtained.

Evidence of differences in behavior between adults and nymphs leads to the conclusion that the sampling techniques studied here are not effective on adults. The vicinus population is mostly adult from mid-October through May in Florida, and sampling with either soap flush or pitfall traps is likely to underestimate the mole cricket population during that time.

Results from movement studies and nutritional studies indicate that ground cover and food supply have surprisingly little effect on mole crickets. The factors determining the amount of detectable movement (i.e., more than local foraging) are population density and nymphal size, although soil moisture and temperature probably have a

general threshhold-type effect on activity. The impression left by the tremendous number of nymphs caught in pitfall traps night after night for extended periods is that vicinus nymphs are constantly on the move if population density is high. The density triggering this increase in activity is somewhere between 11 and 15 nymphs per square meter. Pitfall captures drop off sharply as density decreases below 10 per square meter.

This constant motion also suggests that any aggregation of mole crickets is likely to be short lived. Mole crickets lay their eggs in clutches which average 35 eggs each for vicinus (Hayslip 1943). Females lay as many as 12 clutches in a season, and there is evidence that most individuals do not fly between clutches (Forrest 1985). Such an oviposition pattern could produce pockets of high population density, especially if colonizing females are few and scattered. As the nymphs mature, however, movement of individuals increases and these local concentrations will tend to disperse.

This pattern of infestation means that sample results soon after colonization of an area are likely to be more variable than later (in the second season, for instance), requiring more samples to accurately estimate the population. As the population in an area grows, the nymphs will tend toward a uniform distribution regardless of localized destruction of food supply or ground cover. This

dispersal is accelerated by the tendency of females to be overdispersed during the spring egg laying season.

Obviously, there is still much to be done in the study of mole crickets. These results provide the basis for further work on the quantitative aspects of the ecology and behavior of S. vicinus. The methods described here can be used to gather long term data on population dynamics and colonization patterns and eventually to evaluate the impact of natural control agents.

LITERATURE CITED

Clark, P.J., and F.C. Evans. 1954. Distance to nearest neighbor as a measure of spatial relationships in populations. Ecology 35(4): 445-453.

Forrest, T.G. 1983. Calling songs and mate choice in mole crickets. In D.T. Gwynne and G.K. Morris, (eds.). Orthopteran mating systems, sexual competition in a diverse group of insects. Westview Press, Boulder, CO. 376 pp.

Forrest, T.G. 1985. Oviposition and maternal investment in mole crickets: effects of season, size, and senescence. (in preparation).

Fritz, G.N. 1983. A technique for separating mole crickets from the soil. Fla. Entomol. 66 (3): 360-362.

Hayslip, N.C. 1943. Notes on biological studies of mole crickets at Plant City, Florida. Fla. Entomol. 26(3): 33-46.

Hudson, W.G., and H. L. Cromroy. 1985. Radioisotope labelling of mole crickets. Fla. Entomol. 68(2): (in press)

Kepner, R. L. 1985. Development of toxic bait for mole cricket control. Ph.D. Dissertation. Univ. Florida, Gainesville. (in preparation)

Kleyla, P.C., and G. Dodson. 1978. Calling behavior and spatial distribution of two species of mole crickets in the field. Ann. Entomol. Soc. Am. 71(4): 602-604.

Lawrence, K.O. 1982. A linear pitfall trap for mole crickets and other soil arthropods. Fla. Entomol. 65 (3): 376-377.

Littell, R.C., and R.J. Freund. 1982. SAS for linear models. SAS Institute, Inc. Cary, N.C. 231 pp.

Matheny, E.L.,Jr. 1981. Contrasting feeding habits of pest mole cricket species. J. Econ. Entomol. 74(4): 444-445.

Matheny, E.L.,Jr., R.L. Kepner, and K.M. Portier. 1983. Landing distribution and density of two sound-attracted mole crickets (Orthoptera: Gryllotalpidae: Scapteriscus). Ann. Entomol. Soc. Am. 76(2): 278-281.

Matheny, E.L.,Jr., A. Tsedeke, and B.J. Smittle. 1981. Feeding response of mole cricket nymphs (Orthoptera: Gryllotalpidae: Scapteriscus) to radiolabelled grasses with, or without, alternative food available. J. Ga. Entomol. Soc. 16(4): 492-495.

Nickerson, J.C., D.E. Snyder, and C.C. Oliver. 1979. Acoustical burrows constructed by mole crickets. Ann. Entomol. Soc. Am. 72(3): 438-440.

Poe, S.L. 1976. Reinfestation of treated tomato fields by mole crickets. Fla. Entomol. 59(1): 88.

Reinert, J.A., and P. Busey. 1985. Resistant varieties. Pages 35-40 in T.J. Walker (ed.) Mole crickets in Florida. Univ. Fla. Agric. Exp. Sta. Bull. 846.

Reinert, J.A., and D.E. Short. 1980. Southern turfgrass insect pests with emphasis on mole cricket biology and management. Proc. Fla. Turf-grass Manage. Conf. 28: 33-43.

Reinert, J.A., and D.E. Short. 1981. Present status of mole crickets in Florida. Fla. Turf. 14(3): 5, 7-9, 11.

Schroeder, H.O. 1941. Mole cricket control project, Plant City Florida. Report of control activities, September 1 - December 31. 1940. 75 pp. In unpublished report, U.S. Dep. Agric. Bur. Entomol. Plant Q. (copy on file Div. Plant Ind. Library. Fla. Dep. Agric., Gainesville, FL).

Short, D.E. and P.G. Koehler. 1977. Control of mole crickets in turf. Fla. Entomol. 60(2): 147-148.

Short, D.E. and P.G. Koehler. 1979. A sampling technique for mole crickets and other pests in turfgrass and pasture. Fla. Entomol. 62 (3): 282-283.

Southwood, T.R.E. 1982. Ecological methods. Chapman and Hall, London. 524 pp.

Tsedeke, A. 1979. Plant material consumption and subterranean movements of mole crickets (Orthoptera: Gryllotalpidae: Scapteriscus) as determined by radioisotope techniques with notes on materials for laboratory feeding. M. S. Thesis, Univ. Florida, Gainesville. 72 pp.

Ulagaraj, S.M. 1974. Mole crickets : ecology, behavior, and acoustical communication (Orthoptera: Gryllotalpidae: Scapteriscus). Ph.D. Dissertation, Univ. of Florida, Gainesville. 72 pp.

Ulagaraj, S.M. 1975. Mole crickets: ecology, behavior, and dispersal flight (Orthoptera: Gryllotalpidae: Scapteriscus). Environ. Entomol. 4(2): 265-273.

Ulagaraj, S.M., and T.J. Walker. 1975. Response of flying mole crickets to three parameters of synthetic songs broadcast outdoors. Nature 253(5492): 530-532.

Van Zwaluwenburg, R.H. 1918. Report of the entomologist. Rep. P.R. Agric. Exp. Sta. 1916. pp. 25-28.

Walker, S.L. 1979. Population estimation, damage evaluation and behavioral studies on mole crickets Scapteriscus vicinus and S. acletus (Orthoptera: Gryllotalpidae). M.S. Thesis, Univ. Florida, Gainesville. 83 pp.

Walker, T.J. 1982. Sound traps for sampling mole cricket flights (Orthoptera: Gryllotalpidae: Scapteriscus). Fla. Entomol. 65(1): 105-110.

Walker, T.J. (ed.). 1985. Mole crickets in Florida. Univ. Fla. Agric. Exp. Sta. Bull. 846. 54 pp.

Walker, T.J., and G.N. Fritz. 1983. Migratory and local flights in mole crickets, Scapteriscus spp. (Gryllotalpidae). Environ. Entomol. 12(3): 953-958.

Walker, T.J., R.C. Littel, and Ngo Dong. 1982. Which mole crickets damage bahiagrass pastures? Fla. Entomol. 65 (1): 110-116.

Walker, T.J., and J.L. Nation. 1982. Sperm storage in mole crickets: fall matings fertilize spring eggs in Scapteriscus acletus. Fla. Entomol. 65(2): 283-285.

Walker, T.J, and Ngo Dong. 1982. Mole crickets and pasture grass: damage by Scapteriscus vicinus but not by S. acletus. Fla. Entomol. 65(3): 300-306.

Walker, T.J., and D.A. Nickle. 1981. Introduction and spread of pest mole crickets: Scapteriscus acletus and S. vicinus reexamined. Ann. Entomol. Soc. Am. 74(2): 158-163.

Walker, T.J., J.A. Reinert, and D.J. Schuster. 1983. Geographical variation in flights of mole crickets (Scapteriscus spp.)(Orthoptera: Gryllotalpidae). Ann. Entomol. Soc. Am. 76(3): 507-517.

Williams, J.J., and L.N. Shaw. 1982. A soil corer for sampling mole crickets. Fla Entomol. 65 (1): 192-194.

Wolcott, G.N. 1938. The introduction into Puerto Rico of Larra americana Saussure, a specific parasite of the "changa" or Puerto Rican mole-cricket Scapteriscus vicinus Scudder. J. Agric. Univ. P. R. 22(2): 193-218.

Worsham, E.L., and W.V. Reed. 1912. The mole cricket (Scapteriscus didactylus Latr.). Ga. Agric. Exp. Stn. Bull. 101: 250-263.

BIOGRAPHICAL SKETCH

William G. Hudson was born March 12, 1950 in Birmingham, Alabama, where he was raised. He graduated from Auburn University in 1972 with a Bachelor of Science in mathematics, in 1978 with a Bachelor of Science in zoology, and again in 1981 with a Master of Science in entomology. He married Deborah Waters in 1981, and began work on the Doctor of Philosophy degree at the University of Florida in 1982.

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 and Nematology

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.

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