EMERGENCE PROFILE OF OVERWINTERED BOLL
WEEVILS AND ENTRY INTO COTTON

by

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CHAPTER I

INTRODUCTION

Purpose and Scope

For more than 80 years the boll weevil, Anthonomus grandis Boheman, has been intensively studied in attempts to reduce the damage caused by this insect. In spite of this effort, this pest has been responsible for immense losses and considerable socio-economic change in the southern United States. Through the years many control recommendations have been made, but this insect still remains the key cotton pest in southern cotton. During the 1960's and 1970's the primary approaches to dealing with the boll weevil have been diapause control programs conducted during the fall or multiple applications of insecticide during the growing season.

Diapause control programs that have been properly conducted with adequate insecticide applications over large areas have been effective in suppressing boll weevil populations. However, these programs are expensive because to be effective, large acreages must receive multiple treatments and controversial environmental issues often arise when insecticide is used on an area-wide basis.

The use of insecticides during the growing season has been the primary control technique practiced by individual

producers. This approach to weevil control increases the probability of outbreaks of secondary pests such as the Heliothis complex, which is resistant to many insecticides. The use of multiple applications of insecticide is extremely expensive due to the increased prices of petro-chemical products. In areas characterized by low yields, the intensive use of insecticides is not economically sound. Bottrell and Adkisson (1977) describe this situation as the "crisis phase" in the historical patterns of cotton insect control.

Recent advances in the development of pest management systems offers new hope for effective management of the boll weevil. These systems integrate several control components to deal with the boll weevil problem. However, for pest management programs to be effective, precise information is needed on the basic ecology of the insect. In particular, more information is needed on boll weevil emergence from winter habitat and movement into cotton. This information is necessary to make timing of early season insecticide applications more precise, thus reducing cost and ecological impact, and improving control effectiveness. A better understanding of the spring ecology of the weevil also will enable cultural control techniques to be used more effectively.

Pheromone traps have been used for several years in boll weevil survey programs. However, trap records have

only been of value in detecting the presence of boll weevils and providing a relative estimate of population size. Information on the true relationship between overwintered boll weevil response to traps and colonization in cotton has been lacking. Without accurate estimates of pest populations, pest management programs have no focal point from which to proceed (Bottrell and Adkisson, 1977).

The emergence profile of overwintered boll weevils and their entry into cotton has not been completely defined in any area of the cotton belt. This study was conducted to develop more precise information on the emergence profile of overwintered boll weevils and their colonization pattern in cotton.

Objectives of Study

1. To explore the relationship between cotton phenology and overwintered boll weevil entry into cotton.
2. To determine the emergence profile of overwintered boll weevils.
3. To determine the efficacy of pheromone traps in reflecting overwintered boll weevil entry into cotton and the relationship between weevil response to pheromone traps and cotton.
4. To determine the sex ratio and physiological condition of overwintered boll weevils responding to pheromone traps and cotton.

5. To determine the length of time that overwintered boll weevils remain after initial entry into cotton.

Review of Literature

History of Boll Weevil Infestations in Texas

L. O. Howard in 1894 reported a new insect, Anthonomus grandis Boheman, was attacking cotton in San Diego Co., Texas, and added "It will possibly prove a very important enemy to the cotton crop in the southwest." This new pest, the boll weevil, wasted little time in far exceeding Howard's predictions. Hunter and Pierce (1912) speculated that the boll weevil actually entered the United States from Mexico in 1892. The boll weevil infested area grew rapidly north and east through the cotton growing areas of the south reaching the eastern limit of the cotton belt in 1921 (Coad, et al., 1922).

Although the boll weevil rapidly moved through the southern United States to become the primary pest in cotton, it did not move into the western part of Texas for some years. The western boundary of the infested area in Texas was relatively stable along a line extending from Del Rio across central Texas into Oklahoma for many years (Hunter and Pierce, 1912 and Coad, et al., 1922). The western range of the boll weevil was occasionally extended by fall emigration but permanent infestations did not become established. Dry climate, lack of favorable overwintering

sites, and perhaps the high altitude caused mortality great enough to prevent recurring infestations (Hunter and Pierce, 1912; Pierce, 1913; and Hunter, 1914).

Although the western limit of the boll weevil was relatively stable for about 50 years, occasional infestations were reported in West Texas. Coad, et al. (1922) reported that areas of the eastern Rolling Plains were infested in 1921. Economic infestations were first reported in the Big Bend area of Texas in 1953 (Robertson, 1957), in the northeastern Rolling Plains in 1952 (Rummel, 1970), and in the El Paso area in 1961 (Ridgway and Brazzel, 1961). Boll weevil damage or specimens were collected on or adjacent to the High Plains in 1936 and 1945 (Rummel, 1970). Economic infestations were reported on the High Plains for the first time in 1959 (Rummel, 1970) with the infested area extending into the northern counties by 1961 (Ridgway and Brazzel, 1961). Adkisson, et al. (1964) reported that overwintering boll weevils had survived the winter of 1963-1964 on the High Plains. A diapause control program was initiated during 1964 in the Rolling Plains of Texas to prevent the further westward spread of the boll weevil. To date, this program has successfully prevented the movement of the boll weevil into the High Plains (Rummel, et al., 1975).

Spring Emergence

The emergence profile of boll weevils from overwintering habitats is one aspect of boll weevil biology that has been of particular interest because an understanding of this phenomenon is important in developing effective control procedures. Overwintered weevil emergence has been studied by using hibernation cages and pheromone traps.

Hibernation cage studies.--Hibernation cages have been used by many workers to study boll weevil emergence from overwintering sites. These studies commonly consisted of caging boll weevils in the fall over suitable overwintering sites and observing weevil emergence during the spring. Hunter and Pierce (1912) reported several years of data, concluding that spring emergence was greatly influenced by climatic conditions. Hinds (1925) reported that peak weevil emergence in cages occurred in late April in Louisiana. . . . Gaines (1935) in studies conducted in Louisiana found that in only a few years did weevil emergence extend into July. Reinhard (1943) reported that in central Texas at least 50% emergence had occurred by 15 May. Fye, et al. (1958) stated that from 30% to 90% emergence from overwintering cages occurs by 1 June. Davis, et al. (1967) found that 89% of the spring emergence from hibernation cages had occurred by 1 June in central Texas. However, correlations have been difficult to obtain between emergence profiles obtained from hibernation cage studies and boll

weevil populations found in small cotton. Fenton and Dunnam (1929) reported that at the time of peak weevil emergence in cages, few boll weevils could be found in presquaring cotton. Apparently, emergence of overwintered boll weevils in hibernation cages does not accurately reflect boll weevil activity in cotton during the spring.

Pheromone trap studies.--The discovery that the male boll weevil produces an aggregating pheromone (Keller, et al., 1964 and Cross and Mitchell, 1966) initiated work with pheromone traps to study boll weevil movement. The response pattern of overwintered boll weevils to pheromone traps in the Rolling Plains of Texas reported by Bottrell, et al. (1970), Hardee, et al. (1970), Ridgway, et al. (1971), Boyd, et al. (1973), and Rummel and Bottrell (1976) are very similar to emergence patterns from hibernation cages reported by Sterling (1971). These studies typically show a peak response to traps occurring in mid-May to early June. However, no direct correlation between weevil response to pheromone traps and entry into cotton was established.

Entry into Cotton

Small cotton plots or trap crops have previously been used to study overwintered boll weevil movement into cotton.

Bondy and Rainwater (1942) stated that, in South Carolina, the majority of boll weevils entered trap crops in June. Fife, et al. (1950) substantiated this conclusion in stating that most boll weevils entered cotton after fruiting began. Walker (1966, 1967) reported that peak entry of overwintered weevils into cotton plots in central Texas was correlated with the appearance of squares. However, in those experiments, the cotton plots were maintained in an unnatural state since all boll weevils and large squares were removed from the plants at regular intervals to prevent reproduction. Fenton and Dunnam (1927) in a natural trap crop found a significant relationship between weevil entry into cotton and plant phenology.

Spring Emergence and Entry into Cotton

Walker and Bottrell (1970) compared boll weevil movement into trap crops free of weevils and large squares with boll weevil response to adhesive-coated wing traps (Cross, et al. 1969) baited with male boll weevils. Although these data were based on one year of observations at a low population level, they agreed with other work concerning weevil response to pheromone traps and to cotton plots. Roach, et al. (1971) compared overwintered boll weevil response to male-baited wing traps with weevil movement into a cotton field in South Carolina. They concluded that, as elsewhere,

there was a relationship between weevil entry into cotton and the stage of cotton growth, and that weevil response to pheromone traps was similar to that reported by other researchers.

Response to Cotton Plants

Parencia, et al. (1964) and Smith, et al. (1965) noted that while few overwintered boll weevils could be found in seedling cotton, a definite response was shown to groups of greenhouse grown squaring cotton plants placed in cotton fields. Mistic and Mitchell (1966) and Mitchell and Taft (1966) found that boll weevils responded to caged and uncaged cotton plants, with their response decreasing as the plants matured. Volatile substances extracted from cotton seedlings and squares have been shown to be attractive to boll weevils (Keller, et al. 1963). In related work, Hedin (1976) reported an increase in the emission of volatiles from field grown cotton with the increase in plant fruiting. He concluded that these volatiles may play a part in weevil migration.

Sex Ratios and Physiological Condition

A great deal of research has been reported on the sex ratio of boll weevils in overwintering sites and in cotton. Hunter and Hinds (1905a) found the sex ratio to be about 1:1 in both cotton and overwintering sites, observing a slightly higher concentration of males

in overwintering sites. Hinds and Yothers (1909) reported about 54% of overwintering weevils were males. Brazzel and Newsom (1959) confirmed these earlier observations. Brazzel and Hightower (1960) found a higher percentage of males throughout the year. Walker (1967) showed the sex ratios for overwintered boll weevils entering cotton was approximately 54% males and 46% females.

Cross and Hardee (1968) and Hardee, et al. (1969) reported that the boll weevil pheromone, the basis for response to traps (Cross and Mitchell, 1966) was an aggregating pheromone with equal numbers of both sexes responding. Hardee, et al. (1970) and Mitchell and Hardee (1974) reported that the sex ratios of overwintered weevils captured on traps were slightly weighted toward males, but were similar to other overwintered weevil studies.

Diapause in the boll weevil was reported by Brazzel and Newsom in 1959. They reported that reproduction was initiated in overwintered boll weevils after feeding on cotton squares. Walker and Pickens (1962) confirmed these observations. Mitchell and Hardee (1974) are somewhat con-tradictory in their findings that from 20 to 45% of weevils captured in traps in Mississippi during the spring were in diapause. These weevils were captured before cotton was fruiting, and therefore should have been predominately diapausing weevils.

Duration within Cotton Plots

Hunter and Hinds (1905b) noted little movement of the male boll weevil after entry into cotton. They suggest "...instead of seeking widely for the females, the males are content to wait for them to come their way." Cross and Mitchell (1966) in observing that the female seeks a pheromone produced by the male confirmed those findings. They also noted that females moved greater distances within cotton fields than did males.

CHAPTER II

METHODS AND PROCEDURES

Sites for isolated cotton plots similar to those described by Walker and Bottrell (1970) were selected in Kent County, Texas. Each of three sites was located approximately 1.2 km from commercial cotton fields and situated near dense stands of sand shinnery oak, Quercus harvardii Rydb. Plots at each site were broken up each spring with a Roto-Spader[®], fertilized and if necessary, irrigated shortly before planting. TAMCOT SP-37 cotton was planted in 4 rows, 6 m long in each plot. Because of low night temperatures and high evaporation rates the plots were covered with plastic sheets to promote rapid seed germination.

Three plots of early cotton, planted on April 17, were studied in 1974. In 1975 and 1976 the study was expanded to include a cotton plot planted at the same time as most commercial cotton in the study area as well as an early-planted plot at each of three sites. The early and standard-planted cotton plots at each site were located approximately 45 m apart. Planting dates for the early and standard plots were April 18 and May 15 in 1975, and April 16 and June 1 in 1976, respectively. The plots

were irrigated and fertilized as needed to keep the plants lush and squaring rapidly. Each plot was progressively thinned until plants were spaced at approximately 0.3 m intervals by squaring time and leaves on the plants were thinned frequently to facilitate detection of boll weevils. Inspections were initiated in each plot as soon as the cotton emerged and continued on a weekly basis until small squares appeared, when the inspections were increased to 2 or 3 per week. All fruit showing any indication of boll weevil damage was removed from the plants to prevent boll weevil reproduction, but undamaged squares, blooms and bolls were left on the plants.

In 1974, all boll weevils found in one plot were removed as soon as they were detected. However, in the other two plots, one male and one female boll weevil were marked with Testors Hot Fuel Proof Butyrate Dope® and replaced on the cotton during each inspection. In 1975 and 1976, one male and one female boll weevil were allowed to remain in all plots (after being marked) to more accurately simulate conditions found in commercial cotton fields. Since reproduction within the plots was prevented, unmarked weevils found in the plots during inspections were assumed to be new immigrants. When marked weevils were replaced in the cotton, the color and marking pattern used for each individual was recorded.

During 1975 and 1976 notes were made on the number of times each specimen was recovered in an attempt to determine how long they remained in the cotton plot.

Four Leggett traps (Leggett and Cross 1971) were placed in the vicinity of each cotton plot to monitor the emerging overwintered boll weevil population. The traps were placed approximately 400 m from the plot to eliminate any chance of competition between pheromone traps and cotton. These traps were installed at the time cotton was planted in the plots and were inspected and rebaited with 3 mg grandlure filters (Hardee, et al., 1972 and Bull, et al., 1973) each week.

Boll weevils that were removed from the cotton plots and traps were returned to the laboratory. Each specimen was dissected to determine it's sex, physiological state, and reproductive condition based upon the criteria described by Brazzel and Newsom (1959).

CHAPTER III

FINDINGS AND INTERPRETATIONS

Boll Weevil Entry into Cotton and Plant Phenology

The present study indicates that movement of overwintered boll weevils into cotton is more closely related to plant phenology than any other factor. During the 3-year study, very few overwintered weevils were detected in presquaring cotton. Boll weevil movement into the cotton was coincident with the appearance of the first small squares (flower buds) in the plots (Figure 1). Boll weevil response to the cotton increased as square size and density increased. Overwintered boll weevil response to the fruiting cotton extended over an 8 or 9 week period with the greater number of weevils entering the plots after the appearance of 1/3 grown squares (approximately 0.6 cm in diameter). The peak entry of weevils into the early cotton plots in 1974 and 1976 occurred 3 to 4 weeks after the appearance of the first 1/3 grown squares (Figure 1). During 1975, peak weevil entry into the early plots occurred at the appearance of 1/3 grown squares. Overwintered weevil entry into cotton at the time of or after the appearance of 1/3 grown squares is directly related to the potential degree of population increase since squares of this size are required for optimum

Figure 1.--Comparison of overwintered boll weevil response to pheromone traps and isolated cotton plots, 1974-1976.

development of the immature stages of the insect (Calhoun, 1930). The majority of weevils that entered the cotton plots did so after oviposition sites were available. Overwintered boll weevil entry was detected in only three of the six standard-planted cotton plots. As in the early-planted plots, weevil entry into the standard plots was coincident with the appearance of squares (Figure 1). The small number of weevils which entered the standard plots appears to be a reflection of the reduced size of the overwintered boll weevil population present in July.

Table 1 shows the percent of the overwintered boll weevil population which entered the cotton plots at the time of or after the appearance of 1/3 grown squares. From 63.2 to 99.5% (mean = 81.1%) of the overwintered boll weevils entered the early cotton plots when 1/3 grown squares were present. A similar pattern was noted in the standard cotton plots with a range of 53 to 100% (mean = 76.5%). These data indicate that major colonization of overwintered weevils in cotton coincides with squaring and that a relatively small percent of the total overwintered population enters presquaring cotton.

The relationship between overwintered weevil movement into cotton and the stage of plant growth is further illustrated in Table 2. These data show only a small percent of the overwintering weevil population entering presquaring cotton, with the infestation increasing with

TABLE 1
PERCENT OVERWINTERED BOLL WEEVIL POPULATION
ENTERING COTTON PLOTS AT THE TIME OF OR
AFTER THE APPEARANCE OF 1/3 GROWN
SQUARES^{1/}

Year	Percent Overwintered Boll Weevil Response	
	Early Planted Cotton ^{2/}	Standard Planted Cotton ^{3/}
1974	63.2	---
1975	80.7	53.0
1976	99.5	100.0
Mean	81.1	76.5

^{1/}Boll weevils found in cotton or captured on traps before July 15, when the first F₁ weevils could be expected, were considered overwintered boll weevils.

^{2/}Cotton planted on 11 April, 18 April, 16 April in 1974, 1975, and 1976, respectively.

^{3/}Cotton planted on 15 May and 1 June in 1975 and 1976, respectively.

the appearance of small squares and 1/3 grown squares. The major portion of the overwintered population which entered cotton did so after the appearance of 1/3 grown squares.

TABLE 2

CUMULATIVE PERCENT RESPONSE OF OVERWINTERED BOLL WEEVILS TO EARLY
PLANTED COTTON PLOTS AND PHEROMONE TRAPS AT SEVERAL
STAGES OF COTTON PHENOLOGY

Cotton Phenology	Percent of Overwintered Boll Weevil Population Responding							
	1974		1975		1976		Mean	
	Cotton Plots	Traps	Cotton Plots	Traps	Cotton Plots	Traps	Cotton Plots	Traps
4-6 leaf	0.0	16.7	4.7	59.3	0	15.1	1.6	30.4
6-8 leaf	4.6	36.6	12.5	78.0	0	27.1	5.7	40.1
Very small squares	36.8	62.3	20.3	89.2	0.5	45.4	19.2	65.6
1st 1/3 grown squares	51.7	74.0	54.6	94.2	7.4	65.7	37.9	68.7

Seasonal Entry into Cotton

Boll weevil entry into cotton does not appear to be directly related to time of year. During the 3-year study the earliest date that boll weevils entered early-planted cotton was May 13, in 1975 (Table 3). The latest date that initial response to early plots occurred was June 3, in 1976. Thus, there was a range of 20 days between the first response of boll weevils to early plots. Initial boll weevil entry into standard cotton plots was June 17 (in 1975) and July 22 (in 1976) with a range of 35 days.

TABLE 3

DATE OF ENTRY OF THE FIRST BOLL WEEVIL
INTO COTTON PLOTS IN THE ROLLING
PLAINS OF TEXAS, 1974-1976

Trap Crop Type	1974	1975	1976	Range (days)
Early planted	20 May	13 May	3 June	20
Standard planted	- ^{1/}	17 June	22 June	35

^{1/}No late planted cotton.

The time of peak entry of overwintered boll weevils into the plots also varied from year to year. The peak entry into early-planted cotton plots occurred on July 1, June 17, and July 8, in 1974, 1975, and 1976, respectively (Table 4). Variability in time of peak weevil entry in the

standard cotton plots was greater than in the early cotton. Weevil response to the standard plots reached a peak on June 24 in 1975 while no detectable peak of overwintered weevils occurred in 1976.

TABLE 4

DATE OF PEAK ENTRY OF OVERWINTERED BOLL WEEVILS
INTO COTTON PLOTS IN THE ROLLING PLAINS
OF TEXAS, 1974-1976

Trap Crop Type	1974	1975	1976	Range (days)
Early planted	1 July	17 June	8 July	21
Standard planted	- ^{1/}	24 June	12 Aug ^{2/}	-

^{1/}No late planted cotton.

^{2/}Not considered as an overwintered boll weevil.

Overwintered Weevil Response to
Traps and Entry into Cotton

Initial entry of overwintered boll weevils into early-planted cotton plots coincided with the peak period of weevil response to pheromone traps. During each year a few boll weevils entered the early-planted presquaring cotton during the period of peak overwintered weevil activity as indicated by pheromone traps (Table 5). Initial boll weevil entry occurred within 7 days of the peak response to traps in five of the eight early planted plots. However, even though a relationship does appear to exist between the abundance of weevils (as indicated by traps)

TABLE 5

COMPARISON OF ENTRY OF THE FIRST BOLL WEEVIL INTO COTTON PLOTS
AND PEAK RESPONSE TO PHEROMONE TRAPS IN THE ROLLING
PLAINS OF TEXAS, 1974-1976

Year	Location	Early Planted Cotton			Standard Planted Cotton		
		Initial Entry Into Plot	Peak Response To Traps	No. Days Between ^{1/} Events	Initial Entry Into Plot	Peak Response To Traps	No. Days Between ^{1/} Events
1974	Site 1	23 May	29 May	- 6	-- ^{2/}		
1974	Site 2	17 June	30 May	+17	--		
1974	Site 3	17 June	30 May	+17	--		
1975	Site 1	9 June	12 May	+27	--	12 May	
1975	Site 2	- ^{3/}	12 May	--	--	12 May	
1975	Site 3	12 May	12 May	0	16 June	12 May	+34
1976	Site 1	3 June	10 June	- 7	22 July	10 June	+44
1976	Site 2	17 June	10 June	+ 7	--	10 June	--
1976	Site 3	10 June	3 June	+ 7	22 July	3 June	+49
	Mean			+ 7.75			+42.33

^{1/}Number of days between events expressed as a minus indicates initial entry into cotton occurred before peak response to traps, and a plus indicates initial entry into cotton occurred after the peak response to traps.

^{2/}No standard-planted plots observed in 1974.

^{3/}Dash indicates no response to cotton plots.

and the initial entry into the plots, actual initial entry ranged from 7 days before to 27 days (mean = 7.8) after the peak response to traps. In the standard-planted plots, which were planted about one month after the early plots, the cotton was very small during the peak period of overwintered weevil response to traps. Weevils were not detected in any of the standard-planted plots until squares were present. The initial entry into the standard plots ranged from 34 to 49 days (mean = 42.3) after the peak trap response.

Pheromone traps consistently indicated that peak overwintered boll weevil activity occurred during May or early June. However, boll weevil entry in the early plots had just started when the peak response to traps occurred. As time progressed, weevil response to traps declined and movement into cotton plots increased. Overwintered weevil entry into the early cotton plots consistently peaked 4 to 5 weeks after the peak response to traps (Figure 1). Peak weevil entry into the standard plots occurred 6 weeks following the peak weevil response to traps. Most overwintered boll weevils responded to the cotton plots during a time of very low weevil response to traps. Therefore, when the pheromone traps indicated little overwintered weevil activity, the major overwintered boll weevil colonization was taking place in the cotton plots.

A secondary peak in weevil response to traps occurring 3 to 6 weeks following the major response periods (Figure 1). In 1975 and 1976, these secondary response peaks corresponded with a period of increased weevil movement into the early cotton plots. However, in 1974 the secondary peak response to traps occurred late in the response period to the cotton plot. These secondary weevil response peaks are common in many studies of overwintered boll weevil response to traps (D. R. Rummel, unpublished data). The secondary peaks apparently reflect an increase in the activity of the remaining overwintered boll weevil population that may enter cotton.

A correlation between the cumulative percent response of overwintered weevils to pheromone traps and to cotton plots is shown in Figures 2 and 3. The cumulative percent response of boll weevils to each cotton plot at each inspection after the initial weevil was found was compared with the cumulative percent response to pheromone traps associated with that plot. Observations from eight early cotton plots and associated traps over the 3-year study period were used to plot the regression line in Figure 2. A positive correlation ($r = 0.72$) was shown between the response to pheromone traps and early-planted cotton. By the time 90% of the overwintered weevils had responded

Figure 2.--Relationship between the cumulative percent response of overwintered boll weevils to pheromone traps and to early planted cotton plots.

Figure 3.--Relationship between the cumulative percent response of overwintered boll weevils to pheromone traps and to standard-planted cotton plots.

to the traps, only about 40% of the weevils had entered the cotton. Only 56% of the weevils had entered cotton by the time 95% had responded to traps. A positive correlation ($r=0.99$) was shown between the cumulative percent weevil response to pheromone traps and the response to three standard-planted cotton plots (Figure 3). When 90% of the overwintered weevils had responded to the traps, only 10% of the weevils had entered the cotton plot. About 32% of the weevils had entered the standard cotton plots by the time 95% of the weevils had responded to traps. If the response of overwintered weevils to pheromone traps is an accurate reflection of the relative number of weevils active in any given area, these data indicate that 44% of the weevils found in early cotton plots and 68% of the weevils found in standard-planted cotton were contributed by the last 5% of the overwintering weevil population to emerge. Further, approximately 59% of the weevils found in early cotton plots and 90% of the weevils found in standard cotton plots were contributed by the last 10% of the overwintering weevil population.

The cumulative percent response of overwintered boll weevils to early planted cotton at several stages of plant phenology and pheromone traps (Table 2) further illustrated the factors involved in overwintered boll weevil movement. Although the entry of boll weevils into cotton is closely

linked to plant phenology, emergence from overwintering sites is not. At the time that small squares appeared in cotton, 65.6% of the overwintered population had responded to traps, and 19.2% of the population had entered the cotton, indicating little response to pre-squaring cotton. The activity in the cotton greatly increased with the appearance of squares, while the activity associated with the traps remained stable. These data further demonstrate the close relationship between fruiting cotton and boll weevil entry into cotton, while indicating that emergence from overwintering sites is a relatively stable, seasonally related phenomenon.

Data presented in Figure 4 indicate that the entry pattern of overwintered weevils into cotton is altered when the natural pheromone system is disrupted. In this cotton plot all boll weevils were removed on detection and no marked weevils were returned to the plot. One male boll weevil was found when the first 1/3 grown square was present. This weevil was removed and no additional weevils were detected for a seven day period. During the period June 19-26, the cotton was fruiting heavily and a total of 18 boll weevils entered the plot. These weevils and thus the natural pheromone source were removed immediately and no further weevil

Figure 4.--Comparison of overwintered boll weevil response to pheromone traps and an isolated cotton plot. All boll weevils were removed from the plot during each inspection. Weevil response to traps is expressed as mean number of boll weevils per trap.

entry into the plot was detected. However, in other plots populated with marked boll weevils, overwintered weevil entry continued over a period of several weeks. A comparison of Figure 4 with Figure 1 indicates that after the initial overwintered weevil response to fruiting cotton plants, the production of pheromone serves as the key to major boll weevil colonization.

Sex Ratios and Physiological Condition

Examinations of overwintered boll weevils removed from the cotton plots showed that 54% were males and 46% were females (Table 6). Sex determinations of trap collected weevils indicated that 58% were male and 42% female. The sex ratio for weevils from both sources was very similar, with a slightly higher number of males. There appeared to be little difference in response to pheromone traps or cotton plants due to sex.

Overwintered boll weevils collected from pheromone traps and the cotton plots show striking dissimilarity in physiological condition. Dissections of weevils collected from cotton plots indicate that 46% were in a reproductive state (Table 7). Examinations of weevils collected from pheromone traps showed that only 4.4% were in a reproductive condition. Because the specimens were removed from the cotton plants every 3 to 4

TABLE 6

SEX RATIO OF OVERWINTERED BOLL WEEVILS RESPONDING TO
COTTON PLOTS AND PHEROMONE TRAPS IN THE
ROLLING PLAINS OF TEXAS, 1974-1976

Year	Cotton Plot				Pheromone Traps			
	No. Observed	Male	Female	Percent Male Female	No. Observed	Male	Female	Percent Male Female
1974	116	61	46	57 43	78	51	27	65 35
1975	78	48	30	62 38	1/ -	-	-	- -
1976	193	94	99	49 51	100	53	47	53 47
Total	388	203	175	54 46	178	104	74	58 42

1/Trap records for pheromone trap not available for 1975.

TABLE 7

PHYSIOLOGICAL CONDITION OF OVERWINTERED BOLL WEEVILS RESPONDING
TO COTTON PLOTS AND PHEROMONE TRAPS IN THE ROLLING
PLAINS OF TEXAS, 1974-1976

Year	Cotton Plot			Pheromone Traps		
	No. Observed	Percent Reproductive	Percent Diapause	No. Observed	Percent Reproductive	Percent Diapause
1974	24	62.5	37.5	78	7.5	92.5
1975	20	30.0	70.0	- 1/	-	-
1976	167	45.5	54.4	100	1.3	98.7
Total	211	46.0	54.0	178	4.4	95.6

^{1/}Trap collected weevils were unavailable in 1975.

days, these data indicate that a very short feeding time on cotton squares causes rapid physiological changes in overwintered boll weevils.

Duration within Cotton Plots

During 1975 and 1976 records were kept on 30 overwintered boll weevils that were detected, marked, and then returned to the cotton plots (Table 8). When these weevils were recovered during inspections they were replaced on the plant and the recovery recorded. Female boll weevils showed a greater tendency to leave the cotton plots than did males. Females were recovered an average of 1.45 times and remained in the cotton plots an average of 5.3 days. Males appeared more settled and were found in the plots on several occasions. Males were recovered an average of 3.1 times and remained in the plots for an average of 12.0 days. The assumption was made that when marked weevils were not recovered they had moved from the plot. However, these weevils may have succumbed to some mortality factor (natural death, predators, etc.) which would account for them not being detected. However, no dead marked weevils were recovered from any of the plots. A female weevil marked and released in a cotton plot on 10 June 1976 was recovered from a pheromone trap 400 m from the plot on 1 July. This finding further indicates the tendency of female weevils to move from presquaring cotton or cotton with a very low density of squares.

TABLE 8
 NUMBER OF TIMES RECOVERED AND LENGTH
 OF TIME OVERWINTERED BOLL WEEVILS
 WERE IN COTTON PLOT

Year	Males			Females		
	No. Observed	$\bar{x}$ Times Recovered	$\bar{x}$ Days in Plot	No. Observed	$\bar{x}$ Times Recovered	$\bar{x}$ Days in Plot
1975	9	1.7	6.7	5	0.2	1.4
1976	6	4.5	17.2	10	2.7	9.2
Total	15	3.1	12.0	15	1.45	5.3

CHAPTER IV

SUMMARY AND CONCLUSIONS

The results of the present study show that overwintered boll weevil movement into cotton is closely related to plant phenology. Only a small percentage of the overwintered weevil population which infests cotton enters prior to the onset of squaring. Boll weevil infestation increases as square size and density increase, with major colonization occurring after the appearance of 1/3 grown squares. These findings are consistent with those of Walker and Bottrell (1970), Roach, et al. (1971), and Rummel and Bottrell (1976). Fenton and Dunnam (1927) reported overwintered boll weevil emergence from hibernation cages was approximately 90% complete when squares were first present in early trap crops. They also state that trap crops had accumulated 47% of the entering overwintered weevils at the time that squaring began. Hedin (1976) showed that volatile compounds produced by growing cotton plants reached a peak when square and bloom production was highest, adding further support to the findings of this study.

Data developed in this study indicate that overwintered weevil colonization is not a result of random weevil entry into cotton followed by pheromone production. Rather,

overwintered weevil immigration into cotton appears to be a positive response to squaring cotton with attraction greatly intensified by pheromone production after weevils feed on squares. Evidently, when overwintered weevils do enter presquaring cotton, the quantity and perhaps the quality of pheromone production is not adequate to stimulate colonization.

The response pattern of boll weevils to pheromone traps appears to be an accurate reflection of the activity and relative abundance of overwintered boll weevils. Pheromone trap records from the study area show that the peak period of overwintered weevil activity consistently occurs during late May and early June, several weeks prior to weevil colonization in cotton. The sharp decline in weevil response to pheromone traps which follows the peak response appears to be a reflection of the declining numbers of overwintered boll weevils. Pheromone trap records indicate that in most instances the size of the overwintered weevil population has declined greatly by the time weevil colonization occurs in cotton. For example, in the study area the first 1/3 grown squares usually appear in commercial cotton fields about July 1. Thus, the present study indicates that only a small percentage of the total overwintered weevil population, perhaps no more than 5 to 10%, is primarily responsible for infestation in cotton. Fenton and Dunnam

(1927) referred to that portion of the overwintered population that emerged late enough to infest squaring cotton as the "effective emergence."

While some overwintered weevils which emerge several weeks in advance of squaring may survive to infest cotton, the mortality rate is likely quite high. Howe (1916) and Fenton and Dunnam (1929) reported the mean life expectancy of weevils feeding on seedling cotton to be about 8 days. The longevity of overwintered weevils on seedling cotton in the study area was reported to be 12.7 days (D. G. Bottrell, unpublished data). Overwintered weevils provided with water but no food were found to survive 8 to 10 days after emergence (L. J. Wade and D. R. Rummel, unpublished data). Therefore, when the peak period of overwintered weevil activity, as reflected by response to traps, occurs several weeks prior to the appearance of squares in cotton, the major portion of the population probably does not survive to infest the cotton. Sterling (1971) reported the survival rate for overwintered boll weevils in the study area to be approximately 1% of the total population entering hibernation. Thus, if only the last 10% of the overwintering population is active at the time that 90% of the infestation occurs in cotton, the infestation of cotton results from only a small part of the original overwintered weevil population. Fenton and Dunnam (1927) came to the same conclusions by comparing overwintered weevil response to trap crops and weevil emergence from hibernation cages.

Records from both pheromone traps and cotton plots indicate that overwintered weevil activity extends over a long period. Following the major period of overwintered weevil activity, pheromone traps records consistently showed a secondary peak of activity to occur approximately one month later. The secondary peak always occurred after squares were present in cotton. These data indicate that a portion of the overwintered weevil population consistently emerges late. The consistent late emergence of a portion of the hibernating population apparently serves as a survival mechanism.

The response to traps of approximately equal numbers of both sexes supports the findings of Hardee, et al. (1969) that the boll weevil pheromone is an aggregating and not a true sex pheromone. Boll weevils entering the cotton plots exhibited a similar sex ratio with a slightly greater number of males. Walker (1967) found that the weevils entering a cotton plot in the spring were about equal in sexual responses (males 54%, females 46%). Similar response patterns to both traps and cotton would indicate both the survival rate and activity level of both sexes of overwintered weevils are equal in the spring.

Brazzel and Newsom (1959) reported that oogenesis does not begin until female boll weevils have fed on squares. Walker and Pickens (1962) stated that egg production and

oviposition was initiated after 7 days of feeding on cotton squares. The radical differences in the physiological condition of trap collected weevils and those collected from cotton confirm these findings. These data further demonstrate the close relationship between overwintered boll weevils and the fruiting of the cotton plant.

Female overwintered boll weevils showed a greater tendency to move from plots than did males. Cross and Mitchell (1966) found that female boll weevils do move considerable distances in cotton searching for males. Several marked weevils were not detected on successive inspections, but later reappeared in the plot. If not overlooked during inspections, these weevils apparently left the cotton but later reentered the plot. The movement pattern noted in both sexes correlates with the observed biology of the insect. Since the female responds to a male, her movement within a given area would logically be greater than that of a male. The female also must search for new oviposition sites resulting in increased movement. Searching for oviposition sites is greater in the early spring when square density is low or a very large overwintering population is present. Conversely, the male does not respond to the female, and need only to locate a site where food is present in order to produce pheromone.

While boll weevil response to pheromone traps in the spring is not a direct indication of weevil entry into cotton, trap records do show the relative abundance of weevils in a given area at any time. Therefore, pheromone traps can be of value as survey and prediction tools in pest management programs. Data in the present study indicate that when the peak period of overwintered weevil response to traps and the initiation of squaring occur close together the probability of significant numbers of boll weevils infesting cotton is greatly increased. Conversely, when squares are not produced until several weeks after the peak period of overwintered weevil response to traps, the number of weevils surviving to infest cotton is greatly reduced. These data indicate that where agronomically feasible, delayed planting dates can be used to advantage in boll weevil management programs. With further research, it may be possible to use pheromone trap records to determine the need for delayed planting to reduce overwintered weevil infestations.

Results of the 3-year study also indicate that overwintered boll weevil response to pheromone traps can be used to predict the degree of infestation that will occur in cotton during the early squaring period. During each year of the study there appeared to be a correlation between the numbers of weevils responding to pheromone

traps prior to squaring and the numbers of weevils which entered the cotton plots. Table 9 shows the mean number of weevils captured per trap per week for a 4-week period ending with the appearance of small squares in the cotton plots and the total number of overwintered weevils entering the cotton. When responses to the traps were in excess of 7 weevils per trap per week, a heavy movement of weevils into cotton occurred 75% of the time. When weevil response to traps averaged from 1 to 6 weevils per trap per week, moderate numbers of weevils entered the plots 67% of the time. No overwintered weevils were found in the cotton plots when the response to pheromone traps averaged less than 1 weevil per trap per week during the indicated period. Although general in nature, these data indicate that overwintered weevil response to pheromone traps provides a relative index of the size of the population and can be used to predict the degree of infestation which will occur when overwintered weevils begin entering cotton. With additional research, it should be possible to correlate weevil response to traps with percent square damage occurring during the early fruiting period. A system of this type would enable producers to determine the need for applying insecticide for overwintered weevil control in advance of significant weevil movement into cotton.

TABLE 9

THE TOTAL NUMBER OF RESPONDING OVERWINTERED BOLL
WEEVILS FOUND IN THE COTTON PLOTS COMPARED WITH
THE MEAN NUMBER OF WEEVILS RESPONDING TO
ASSOCIATED TRAPS IN A FOUR WEEK PERIOD
ENDING WITH THE APPEARANCE OF
SMALL SQUARES IN THE COTTON

Mean No. Weevils/Trap/ Inspection	Total Overwintered Weevils to Respond To Cotton	Degree of Response to Cotton
15.9	58	
14.9	51	
13.7	1	Heavy
10.9	70	Response
10.1	59	to 75%
8.5	35	of Plots
7.3	1	
7.1	54	
4.3	0	Moderate
1.8	16	Response to
1.6	10	67% of Plots
0.6	0	No Response
0.6	0	to Plots

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