BOLL WEEVIL IMMIGRATION INTO WINTER
HABITAT AND SUBSEQUENT SPRING AND
SUMMER EMERGENCE

by

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INTRODUCTION

Purpose and Scope

The boll weevil, Anthonomus grandis Boheman, is a key pest of cotton in the United States. Cross (1973) estimated that producers lose \$200 million annually to the boll weevil. Almost one-third of all insecticides applied to crops is used to control this pest at an additional cost of \$75 million annually.

The geographical distribution of the boll weevil in Texas has expanded greatly during the past two decades. During recent years the weevil has spread throughout the Rolling Plains and into the eastern and southern margins of the High Plains, threatening production in one of the largest cotton growing areas in the United States.

Adkisson et al. (1965a) reported a small percentage of boll weevils survived the winter of 1963-64 in hibernation cages placed on various ground trash in the High Plains. Previously, entomologists believed that the boll weevil could not survive the normally severe winters on the High Plains due to the lack of overwintering habitat normally associated with this insect (Bottrell et al. 1972a).

In 1964, a large scale control program was initiated to combat boll weevil infestations occurring along the eastern edge of the High Plains and to reduce the possibility of

farther westward spread of the insect. The program was started in September of 1964 and covered an eight county area along the "Caprock," an escarpment which defines the eastern edge of the High Plains. The objective was to reduce, by aerial applications of the insecticide malathion, the number of boll weevils normally spending the winter as diapausing adults. The feasibility of such a program had been demonstrated by Brazzel et al. (1961) in a pilot project located in the Big Bend area of Texas. This study demonstrated that early season infestations of boll weevils could be greatly reduced with insecticide applications made the previous fall. In the 1964 High Plains diapause control program, it was estimated that the potentially overwintering weevil population was reduced by 82% (Adkisson et al. 1965a).

The control program was modified during 1965 into a two-phase, or reproductive-diapause control approach (Adkisson et al. 1965b, 1966). The first phase of this suppression technique consisted of three insecticide applications made at approximately 5-day intervals and was designed to destroy reproductive females before they deposited eggs which would develop into diapausing adults. The second phase consisted of four applications of insecticide aimed at eliminating diapausing adults which escaped the phase one applications and those which emerged after completion of phase one. Adkisson (1965b) reported a 99% reduction of potentially overwintering adults was obtained by this program in 1965.

The High Plains reproductive-diapause control program

has been in continuous operation for 13 years with a great deal of success. The westward movement of the boll weevil has been stabilized with only a slight increase in its western limit in the southeastern portion of the control zone in 1967-69 (Bottrell et al. 1972a). This suppression technique has been demonstrated as a highly effective tool in combating boll weevil populations with a minimum of environmental impact (Rummel et al. 1975a). This technique has been used as a component of the trial eradication effort (Eden 1973) and is currently being implemented in several locations throughout Texas for boll weevil control.

A limiting factor to a reproductive-diapause control program is the expense of insecticide applications to the large cotton acreages involved in most instances. Most suggestions for improvement of reproductive-diapause control programs require the phase one portion to begin in August for maximum suppression of the potential overwintering population (Rummel and Adkisson 1971, Taft et al. 1973, and Mitchell et al. 1973). However, starting in August would entail even greater expense due to the increased number of insecticide applications required. The early starting date also creates a danger of secondary pest outbreaks when insect predators and parasites are destroyed by the early applications.

When suppression of diapausing weevil populations is used as a pest management technique, economic considerations will usually limit the number of insecticide applications used

in the fall. In a pest management program it would be important that these limited insecticide applications be timed for maximum benefit. One objective of this study was to determine boll weevil emergence patterns in the spring as influenced by the time of entry into overwintering habitat in the fall. Another objective was to ascertain the relative survival rates of boll weevils entering winter quarters at different times during the fall. The third objective was to determine the time in the fall maximum build-up of diapausing boll weevils occurred in overwintering habitat. A knowledge of these relationships is essential to the effective scheduling of insecticide applications aimed at suppressing prehibernating boll weevil populations.

Review of Literature

Initial Entry into the United States

The boll weevil entered the United States from Mexico and was first reported in Texas near Brownsville in 1894 (Howard 1894). The weevil spread rapidly through the southern states and by 1921 had reached the limit of cotton cultivation in the United States except for western Texas, southwestern Oklahoma, northeastern North Carolina, and Virginia (Coad et al. 1922). By 1906 the westward movement of the weevil had stabilized in Texas (Figure 1) along a line stretching from near Del Rio across central Texas and into southern Oklahoma (Hunter and Pierce 1912). Unfavorable conditions such as dryness of climate (Hunter 1914) and lack of suitable overwintering

Fig. 1. Map illustrating boll weevil movement through Texas and into the High Plains. Counties included in the original High Plains diapause control program of 1974 are shown along with areas treated in the 1977 reproductive-diapause control program.

habitat (Hunter and Pierce 1912) appeared to restrict further westward spread of the insect for a number of years.

Movement onto West Texas

Robertson (1957) reported damaging infestations of the insect in 1953 near Presidio, Texas (Figure 1). These infestations were more than 322 km west of previously detected damage. During this same time period boll weevil infestations were becoming established in Collingsworth county in the northeastern Rolling Plains (Rummel 1970). Sporadic infestations of boll weevils had occurred in the Rolling Plains as early as 1936 but these populations did not become established (Rummel 1970).

The first significant boll weevil infestations found on the High Plains were reported from Crosby and Dickens counties during the fall of 1959 (Rummel 1970). Infestations on the High Plains persisted and in 1961 damage was reported from Briscoe, Floyd, and Crosby counties (Ridgway and Brazzel 1961). By the fall of 1963 boll weevils had migrated to the western portions of Briscoe, Floyd and Crosby counties causing moderate to heavy infestations. Boll weevils were successfully overwintered in hibernation cages on the High Plains during the winter of 1963-64 demonstrating their ability to survive until the next cotton production season in this geographic region (Adkisson et al. 1965a).

As previously mentioned, a large scale control program was initiated during the fall of 1964 to stop the westward

spread of the boll weevil into the High Plains and into other cotton producing states in the West. This control program has been expanded over the years to include portions of 16 High and Rolling Plains counties (Figure 1). These control efforts along the eastern edge of the High Plains have slowed the westward expansion of this insect to a great extent. However, Bottrell et al. (1972a) reported low level infestations in Gaines and Andrews counties during the fall of 1968. During 1977 boll weevils were detected on pheromone traps in Gaines and Yoakum counties (Roy Moritz, personal communication). These weevils represent a portion of the fall population immigrating from the South and East. At the present time there are no indications of firmly established populations in either Gaines or Yoakum county (Don Rummel, personal communication). However, capture of weevils on pheromone traps in Gaines and Yoakum counties indicate these areas to be the western limit of boll weevil movement into the High Plains.

Spring Emergence Patterns

Calhoun (1931) was the first to study the relationship between time of boll weevil entrance into hibernation sites and the date of their emergence the following spring. With the use of hibernation cages, he concluded that the date weevils were confined in the autumn did not influence the date of emergence the following spring. Sterling (1971) found no relationship between the time boll weevils were placed in hibernation cages and the time they emerged in the spring.

Taft et al. (1973) proposed that in South Carolina an effective reproductive-diapause control program should begin by mid-August. They based this proposal on a study which indicated no relationship between the time boll weevils entered hibernation sites, their winter survival, or the time of their emergence in the spring. Mitchell et al. (1973) reported a correlation between the time boll weevils entered hibernation and the time of emergence the following year. They stated that "the late-emerging weevils apparently had gone into diapause early, and the early emerging weevils were those that were late in the fields." Based on this information, they recommended reproductive-diapause control programs begin early to prevent boll weevils from entering overwintering habitat in August and September. These cited studies indicate that it is necessary to control diapausing boll weevils during the late summer and early fall to prevent their entry into overwintering habitat.

Winter Survival

Hibernation cages were widely used in the past to study winter survival of the boll weevil. Generally, weevils were introduced into cages placed over suitable overwintering habitat and the subsequent spring emergence recorded. Sanderson (1907) first observed survival rates in East Texas which ranged from 2.5% to 15%. Other reports of winter survival ranged from 4% to 7% at College Station, Texas (Reinhard 1941, Walker and Brazzel 1959).

Fenton and Dunnam (1927) reported an average winter survival of 3.27% in South Carolina. They found the greatest survival (15.8%) came from weevils introduced into cages during late-November compared to no survival of weevils installed in early September. In a continuation of this study, Bondy and Rainwater (1942) found that from 1931 to 1941 the average survival for weevils installed in hibernation cages during mid-November to be more than twice that for mid-October installations. Support for these investigations comes from cage studies conducted in Florida where the lowest survival was from boll weevils installed early in the fall (Calhoun 1931).

Adkisson et al. (1965a) first reported the survival rate of boll weevils in the High and Rolling Plains area. They found that 0.06% of local weevils survived the winter on the High Plains. In the Rolling Plains where more suitable overwintering habitat is available, the survival rate was 0.7%. Sterling (1971) reported a similar survival rate of 1% from hibernation studies conducted near Spur, Texas in 1966. His work indicated the highest survival came from weevils installed in cages between October 15 and November 3 with a maximum survival rate of 3.8%. Taft et al. (1973) allowed boll weevils to naturally enter uncovered hibernation cages and found the best survival occurred when weevils entered the cages during late-November. These hibernation cage studies suggest that boll weevils entering overwintering sites in August, September, and early October have a greatly reduced chance of surviving to the next cotton production season.

Immigration into Winter Habitat

Early studies of the boll weevil indicated that active movement into overwintering quarters resulted from a lack of proper food and low temperatures during the fall (Hinds and Yothers 1909, Hunter and Pierce 1912). However, Brazzel and Newsom (1959) demonstrated that adult boll weevils enter diapause instead of becoming inactive as a response to low temperatures in the fall. They found diapausing adults in overwintering sites as early as August in Louisiana. Boll weevils have been found in winter habitat during every month of the year except July (Brazzel and Newsom 1959, and Beckham 1963).

Lloyd and Merkl (1961) found low numbers of diapausing weevils moving into ground trash during September, well in advance of freezing weather. Mitchell and Mistic (1965) demonstrated that diapausing boll weevils began entering overwintering sites near treated cotton during September with entry increasing steadily through October and November. Near untreated cotton they found boll weevils in ground trash during August, but numbers declined during October and November indicating some boll weevils died before the onset of winter. Beckham (1963) found in Georgia that weevil movement into overwintering habitat begins in October with the numbers present increasing steadily until winter mortality begins.

Pheromone trap records in the Rolling Plains of Texas

show that late season migration of the boll weevil begins about mid-August and continues until frost (Bottrell et al. 1970, Ridgway et al. 1971, and Rummel et al. 1975b). Weevil response to traps during this period shows two distinct periods of activity. Weevil response first peaks in September, declines slightly, and then rises to another peak in October. Previous research has indicated that the fall migratory population is divided into two distinct segments. The first segment consists primarily of reproductive weevils and peaks approximately mid-September. The second segment is largely composed of diapausing weevils and peaks in late October (D. S. Moody, unpublished data). Rummel et al. (1975b) found that peak immigration of diapausing weevils into a small isolated cotton plot, located approximately five km from commercial cotton, did not occur until after October 24. It is evident from these data that the majority of the diapausing population is not migrating during September and early October, only appearing in large numbers about mid-October.

Previous studies have not clearly defined the peak periods of diapausing weevil entry into winter habitat. Most hibernation cage studies indicate that weevils entering winter habitat late in the fall exhibit the highest survival rate. However, cage studies have not provided information on the seasonal entry into overwintering quarters under natural conditions. Mitchell et al. (1973) indicated that weevil entry into winter quarters during the late summer and early fall was great enough to warrant beginning diapause control programs at that time.

METHODS AND PROCEDURES

Beginning in July of 1974 and 1975, boll weevil infested cotton squares were collected from plants and placed in 0.946 liter ice cream cartons. A 25x95 mm glass vial was inserted in each carton for collection of emerging adults. Square collections were made on a weekly basis throughout the late summer and fall. Adults emerging during the same weekly period were held together as a unit in 30x31x30 cm aluminum screen wire cages.

Release units of boll weevils were maintained for three weeks under a photoperiod corresponding to that found in nature by the use of photoelectrically controlled lights. A constant temperature of 24°C ($\pm 2^{\circ}\text{C}$) was maintained in the emergence chamber. Fresh, small, green cotton bolls were provided daily as the primary food source during the maintenance period. At the end of three weeks, 20 boll weevils from each release unit were dissected and examined to determine their diapause status based on the criteria of Brazzel and Newsom (1959).

Boll weevils were released on a weekly basis from September 1 of each year until frost. All released boll weevils were allowed to acclimate to conditions at the release site for a short period of time and then were placed directly onto the ground surface. The release site was a 10-15 m diameter grove of sand shinnery oak, Quercus havardii Rybd., located in a rangeland community of this vegetation in Stonewall county, Texas.

The ground surface within the grove was covered with a dense accumulation of leaves and other plant debris. Sand shinnery oak has been shown to be the primary overwintering habitat for boll weevils in the Rolling Plains of Texas (Rummel and Adkisson 1970, and Bottrell et al. 1972b). Therefore, the habitat was chosen as a release site because it best simulated conditions that would be encountered by native overwintering boll weevil populations.

Before transportation to the field, each release unit was identified by individually marking boll weevils with the same color code of Testors[®] butyrate dope (Cross and Mitchell 1964) or a supersaturated solution of Day-Glo[®] powder in acetone (D. G. Bottrell, unpublished data).

During 1974 a total of 8,895 boll weevils were released. Of this total 2,422 weevils were released in September, 5,070 in October, and 1,403 in November. The releases made during 1975 totaled 15,313 with 9,519 being released in September, 3,634 in October, and 2,160 in November. The maximum number of boll weevils available were placed in the overwintering site on each release date. However, the availability of infested squares and subsequent weevil emergence differed from week to week during the collection period. This resulted in a variable number of boll weevils available for release during different months in the fall.

In January 1975, Leggett traps (Leggett and Cross 1971) were placed in two concentric circles of eight traps each around the release site. The radii of the two circles of

traps were 30 and 90 m, respectively. Four traps were placed within two m of the release site at the four cardinal directions. During 1976, the outer circle of traps was moved to the two m location because of poor recapture rates obtained at the 90 m location. During both years, one trap was located in the exact center of the release site. Traps were inspected and rebaited at weekly intervals from January until September during each year. Traps were baited with a three mg physical barrier formulation (Bull et al. 1973) of grandlure (Hardee et al. 1972), the synthetic pheromone of the boll weevil. All boll weevils captured in 1975 and 1976 were visually examined for evidence of marking material. Recaptured boll weevils were held individually in 29 cc medicine cups and provided only water to determine their longevity in the absence of food. To equalize the variability between numbers released during different months in the fall, all recovery data were transformed to reflect the number of boll weevils captured/1000 released during September, October, and November. These data were then subjected to a statistical analysis of variance and the means separated according to Duncan's multiple range test.

Boll weevil movement into overwintering habitat was monitored by leaf litter examinations made on a weekly to bi-weekly basis during the period August 1975 to March 1977. These examinations were made in dense sand shinnery oak leaf litter surrounding a cotton field approximately two km from

the release site. Approximately 30 m² of leaf litter was examined at each inspection. The number of boll weevils per hectare of ground litter at each inspection was calculated and plotted to determine if boll weevils naturally entered hibernation during the same time frame as those artificially released. Leaf litter examinations were made in a similar manner to that used by Bottrell et al. (1972b).

RESULTS AND DISCUSSION

Winter Survival

A total of 24,208 boll weevils were released during 1974-75, and of this total 239 (0.987%) were recaptured during the spring and summer of 1975 and 1976. Of the 239 weevils recaptured, 99 came from September releases, 81 from October releases, and 59 from weevils released in November. These data expressed as a percentage of the number released each month show that the smallest recovery, 0.83%, came from boll weevils released in September. The recovery rate of boll weevils released in October was 0.93%; while the greatest recapture (1.66%) came from boll weevils released in November. The greatest winter survival as indicated by the percentage recovery came from boll weevils released later in the fall (Table 1).

Table 1. Number of boll weevils captured in pheromone traps during the 1975-76 emergence periods in Stonewall Co., Texas.

Month of Release	Number Released ^{a/}	Total Recaptured	Percent Recaptured
September	11,941	99	0.83
October	8,704	81	0.93
November	3,563	59	1.66
Total	24,208	239	0.987

^{a/}Numbers presented here are the total of releases made in 1974 and 1975.

Release Study

Boll weevils released during the experiment ranged in diapause status from 71 to 100%. The diapause status for weevils released in September averaged 90% and boll weevils released during October and November averaged 89% and 94%, respectively (Table 2).

Table 2. Percent diapause of boll weevils released into overwintering habitat, 1974-75.^{a/}

Month	Year	Week					$\bar{X}$
		1	2	3	4	5	
Sept.	1974	80%	95%	71%	95%	-	90%
	1975	85%	90%	100%	100%	100%	
Oct.	1974	74%	95%	100%	83%	100%	89%
	1975	83%	-	85%	90%		
Nov.	1974	-	100%	100%			94%
	1975	95%	95%	95%	80%		

^{a/} No diapause determinations were made on dates where dash appears. No data indicates no release made during week.

The capture of marked weevils on pheromone traps occurred primarily during April through July of each year. During this time period 236 of the marked weevils were recaptured. In 1975 one boll weevil from the November releases was found on August 26 during a routine field inspection in cotton two km from the release site. Two other boll weevils released in October of 1975 emerged in February after several days of

warm weather with temperatures ranging around a high of 31⁰ C.

The monthly distribution of boll weevils recaptured during the major recovery period, April through July, is shown in Figure 2. The peak recapture of weevils released during September occurred during May of the following year with response to traps declining to a low level in July. The recapture of October released weevils increased gradually through May to a peak in June and then dropped to a low level in July. There was no significant difference between the number of September and October released weevils recovered during any month of the recapture period. However, there appeared to be a slight trend indicating that October released weevils were more active later in the spring and summer than boll weevils released in September. Boll weevils released in November responded to traps the following season in a similar manner to those released in October, with the recapture rate increasing from an April low to a peak in June. Recovery of November released weevils then dropped in July to a level similar to that found in May. The number of November released weevils recovered during June and July of the following year was significantly greater than the number recaptured from the September and October releases (Figure 2).

Overwintering Habitat Examinations

Overwintering habitat sampling data (Figure 3) indicate that in the study area the major portion of the overwintering

Fig. 2. The mean monthly distribution of marked boll weevils captured in pheromone traps during the spring and summer of 1975 and 1976 following release into winter habitat. Means within the same month of recapture followed by the same letter are not significantly different at the 5% level according to Duncan's multiple range test.

Fig. 3. Number of boll weevils present in the winter habitat during the period August 1975 to March 1977.

population naturally enters hibernation during October and November. These data show that no weevils were detected during August, but 1,395 boll weevils per hectare were present in overwintering habitat during September 1975. During October the number of weevils in hibernation sites increased 13 fold to a mean of 18,896/ha. The number continued to increase in November to a mean of 24,995/ha. The greatest number found during this period was 35,878/ha on November 7. A steady decline in weevil numbers occurred after the first killing freeze on November 13, 1975.

An extremely mild winter during 1975-76 resulted in only a 75% reduction of the overwintering population from the November peak when comparisons were made to weevil numbers in leaf litter examinations in March 1976. This high survival resulted in extremely large field populations, ranging up to 16,370 overwintered weevils per hectare, during early July 1976 in cotton adjacent to the sampling site. Because of the large field populations which developed during the summer, the numbers of boll weevils entering winter habitat during the fall of 1976 were greater than those entering in 1975.

The results of the 1976-77 overwintering habitat examinations were similar to those of 1975-76 (Figure 3). Examinations of hibernation sites revealed that a mean of 8,252 weevils per hectare were present in surface leaf litter during September. This figure increased four fold to a mean of 33,965/ha during October. The greatest number of weevils found during

this period was 44,251/ha on October 12, 1976. An early cold front moved through the area on October 8, 1976, and temperatures ranged around 1°C for several days. Following the cold front, an unusually early freeze accompanied by approximately 3 cm of freezing rain, occurred on October 20. After this, the number of boll weevils found in overwintering sites declined rapidly. Apparently the early freezing weather prematurely reduced the number of weevils moving into hibernation sites and increased the mortality of those already present in winter quarters. It is likely that weevils would have continued their movement into overwintering habitat until mid-November, which is the average freeze date, if the unseasonably cold weather had not occurred. During both years, the number of weevils detected in leaf litter gradually declined throughout the winter and spring. However, some weevils were found in overwintering habitat during every month of the year except August. In September, there was a sudden increase but the most rapid build-up of overwintering weevils in overwintering habitat occurred during October and November.

SUMMARY AND CONCLUSIONS

Data developed in this study indicate that diapausing weevils which enter overwintering habitat during the latter half of the fall period have a higher survival rate and tend to emerge later the following growing season than boll weevils which enter overwintering sites early.

These data differ with those of Mitchell et al. (1973) who indicated that weevils going into hibernation sites early were most likely to emerge late the following year. However, the different experimental techniques used account for the apparently different conclusions derived from the two studies. Mitchell et al. (1973) released marked, field collected weevils back into cotton during the late summer and fall period. Their pheromone trap capture data showed that weevils released in August and September tend to emerge later during the following growing season than weevils released in October and November. However, it was not known when these weevils actually left the cotton fields and entered overwintering habitat.

In planning of fall boll weevil suppression programs the time that diapausing weevils appear in cotton is not as critical a factor to consider as the time these weevils actually move into the winter habitat.

Results of the present study show that the major accumulation of overwintered weevils in hibernation habitat occurs during October and November in the study area. Although diapausing

weevils are present in cotton during the late summer and early fall period, it appears that active movement into hibernation sites occurs later in the fall. Apparently only a small percentage of the total diapausing population actually enters overwintering habitat during late August and early September.

The association between the time of diapausing weevil entry into winter habitat and the time of emergence the following growing season is an important factor to consider in conducting late season boll weevil suppression programs. Research has shown that the major colonization of overwintered weevils in cotton occurs after the appearance of 1/3 grown squares (Walker and Bottrell 1970, and White and Rummel 1977). The mortality rate of weevils emerging well in advance of squaring cotton is quite high. Howe (1916) and Fenton and Dunnam (1927) reported the mean life expectancy of weevils feeding on seedling cotton to be approximately 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). In the present study, overwintered weevils lived 8 to 10 days after emergence when provided only with water. Cotton squares (1/3 grown or larger) which are suitable for oviposition and complete development of the boll weevil usually appear in commercial cotton about 1 July in the study area. Therefore, there is likely a high mortality rate among weevils emerging

even as late as mid-June. This study indicates that diapausing weevils which enter overwintering habitat during the late fall will have the greatest impact on cotton the following year since they tend to emerge near or after the time cotton begins fruiting.

The application of insecticide during the fall to destroy diapausing boll weevils before they enter overwintering habitat has proven to be a highly effective population suppression technique in many cotton producing areas. The reproductive-diapause approach (Adkisson et al. 1965b, 1966, Lloyd et al. 1966, and Rummel and Adkisson 1971) which was used in the pilot boll weevil eradication experiment (Eden 1973) is the logical approach if maximum suppression of the weevil population is the objective. However, this technique is expensive because of the large number of insecticide applications required. The early starting date also creates a danger of secondary pest outbreaks when insect predators and parasites are destroyed by the early applications.

If the suppression of diapausing weevil populations is used as a pest management technique, the program initially outlined by Brazzel et al. (1961) which utilizes only three to five applications is the logical choice. In pest management programs, economic considerations will usually limit the number of insecticide applications used for weevil suppression in the fall. It is important that these applications be timed for maximum benefit. The results presented here indicate that field populations of weevils in the study area, and areas of similar climatic conditions,

should be subjected to maximum insecticide pressure during the latter half of the fall period when major entry into overwintering habitat occurs. This program is aimed strictly at destroying diapausing weevils before they leave cotton and enter overwintering habitat. The portion of the population that does enter overwintering sites during August and early September tends to emerge early the following season and therefore may have less impact on the developing cotton crop than weevils which enter the winter habitat late. This type late season control program coupled with other management techniques can provide producers in some localities with a sound, economical, area-wide management system for the boll weevil.

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