earliest time that armyworms could be expected to make an appearance. The maximum developmental time could also be calculated from the end of the first flight, and the latest date of expected outbreaks could be ascertained from life history knowledge. Although a prediction that an armyworm outbreak is inevitable is not possible from such information, limiting dates can be set. In other words, a statement could be prepared to the effect that "if armyworm damage is to occur this season, it will come between May 15 and June 5." From this information, the county agent could warn all grain farmers in his county to search for developing armyworms in his fields at periodic intervals from the week of May 8, through June 5. Along with the warning statement, details of survey methods should be included as well as instructions for evaluation of the survey results, *e. g.*, in a field where five or more immature "worms" per square foot are found, immediate control measures should be taken. This timing of application would prevent major damage, since it is established that only mature worms are capable of inflicting serious losses. Such a system would require a breakdown of the state into natural climatic areas. In Tennessee, for example, probably West Tennessee, Middle Tennessee, lower East Tennessee (low altitudes), and upper East Tennessee (higher altitudes) would be sufficient division. However, the final division should be based on a review of long-time weather data. Once this has been done, light traps should be placed in operation in early March in the larger grain-growing areas of each climatic division. The date of the first moth flight could then be determined for each area, the minimal developmental time calculated from that area, and the warning system put into effect.

Let us consider a test case for the application of such a system from data available in this work. From the data in table 5, page 284, it is seen that the first heavy flight of moths came in lower East Tennessee (Knox, Blount, and Monroe counties) by the week ending April 22, 1957, so that April 15 is the earliest date of heavy moth activity in the area, and April 29 is the latest date. Therefore, egg deposition could not have begun before April 15 and must have been completed by May 7 (tables 5, page 284, and 12, page 292). From this knowledge, the following calculations can be made.

We know from table 14, that a minimum of three and a maximum of fifteen days are required for egg hatching during this period. From table 16, page 301, we know that a minimum of fifteen and a maximum of sixteen days are required for larval development to the sixth instar. Therefore, from April 15, the earliest date of adult activity, a minimum of eighteen days can be expected before mature armyworms could appear in the field, and from May 7, the latest date of adult activity, a maximum of thirty-one days can be expected until all larval damage must have been done. Therefore, a statement might be made as follows: "If armyworm damage is to occur this season, it will be between May 3 and June 8." On the strength of this statement, searches should be made from April 26 through June 8. A look at table 29 will show that the first armyworms were found on May 3, 1957, in Blount County, on May 6 in Monroe County. If the Monroe County agent had been told to warn his farmers to search for armyworms beginning with the week of April 23, 1957, and his advice had been followed, then incipient outbreaks would have been detected in ample time for control measures to be applied where necessary. Also, after June 8, 1957, no searching would have been necessary, since the critical period had subsided by that time. The same technique could be employed in other areas of the state and in other states.

It is hoped that this discussion will serve to show the value of life history and seasonal cycle knowledge of this species. The same type of knowledge might also prove useful in the control of other species of insect pests. The fact that the armyworm seldom, if ever, is destructive for two successive generations in an area suggests the advisability of widespread use of such a warning system. Only the damaging brood and fundamental life history knowledge for that brood need to be known for the successful application of the system in an area.

An armyworm outbreak is evidently an unnatural occurrence and appears to be disadvantageous to the species. When the biotic system of which the armyworm is a part is in equilibrium, the population remains approximately stationary over a considerable period of time and the individuals making up the population behave as do other solitary noctuids. Only when environmental resistance is low does the species reach enough of its potential to produce outbreaks.

If we consider the total resistance to be made up of physical resistance (climate) and biotic resistance (natural enemies), the role of natural enemies might be discussed in a more favorable light. It must be assumed that when an armyworm outbreak occurs, either total resistance, physical resistance, or biological resistance is low. Therefore, if biotic resistance could be determined by natural enemy surveys and physical resistance by past conditions associated with outbreaks, and put on a quantitative basis, there might be a basis on which to attack the problem of causative factors of outbreaks. At present this information is not available and the effect of the natural enemy complex on the population in respect to outbreak cause cannot be determined, since it cannot be distinguished from physical resistance. Two important things, however, are known — that parasites lag behind the armyworm and that the moths are not affected. Therefore, it seems that an outbreak must be initiated as a result of lowered physical resistance to the moth which deposits a maximum of eggs of which a large percentage must hatch. If physical resistance to the larvae were high, then no outbreak could occur, even though egg production were high, nor could parasites build up without a maximum number of hosts. Thus, we must conclude that an outbreak must begin in an environment of low physical resistance. It appears then, that natural enemies cannot prevent a first brood outbreak, and that their role must be one of minimizing damage and reducing the armyworm population once again to equilibrium which, after all, is favorable to the host and consequently to the parasite itself. The major parasites, tachinid flies and braconid wasps, fit nicely into this picture. Neither can build a large population except when hosts are numerous. The braconid wasps deposit their eggs in young armyworm larvae, but reach maturity only after the armyworms are nearly grown. Thus they cannot appear in sufficient numbers to be an important factor in controlling the tarmyworm until a major amount of damage has already been done by the host. It has been shown, however, by Tower (1916) that armyworms parasitized by the braconid, *Apanteles militaris,* eat approximately one-half as much food as do non-parasitized worms. Thus, this species serves to minimize damage during the outbreak period and the large numbers of adults, as many as one-hundred from a single host, help to reduce the armyworm population in the succeeding generation. The tachinid flies attack, for the most part, only nearly full grown armyworm larvae and are therefore of little benefit against the generation attacked. However, the host is inevitably killed so that the parasite is effective in cutting off a subsequent brood of armyworms.

Infectious diseases and predators seem to have a similar role in their effect upon an armyworm population, that of maintaining stability when the armyworm, by lowered physical resistance, becomes so numerous that an outbreak results.

SUMMARY

The purpose of this paper is to report findings on the fundamental biology of the armyworm, *Pseudaletia unipuncta* (Haworth), based on a two-season study in Tennessee (1956-57).

Data were obtained from a combination of direct field observations. detailed insectary colony rearings, extensive light trap operations, and several controlled laboratory experiments.

Background material for the study is presented and includes a review of the literature, both the general and systematic histories of the species, geographical distribution, and known host plants.

The general life-history is given for Tennessee along with a general description of the various life history stages and detailed biological data associated with those stages.

A key is presented for separating closely related species in Tennessee. All noctuid species which sometimes assume the armyworm habit are listed with their host plants and distribution.

A detailed account is given of the seasonal cycle of the armyworm in Tennessee with emphasis on the overwintering status of the species in the state.

A section is included on the natural enemies of *P. unipuncta* in which known parasites are listed and notes are included on those species reared by the writer. A summary of known predators and diseases of the armyworm is included.

The principal findings of this study are as follows:

1. There are five annual broods of the armyworm in Tennessee of which only the first brood is likely to be damaging to crops.

2. Any damage resulting from the armyworm in Tennessee is likely to occur not later than the first week of June of a given year.

3. The fifth brood enters the winter in the partially grown larval stage and is capable of surviving Tennessee winter conditions.

4. Larvae which enter the winter season in their middle instars have the best chance of overwintering in Tennessee.

5. The armyworm is able to arrest development during extended cold periods, resuming normal activities during warm periods of winter, thereby extending developmental time which results in successful overwintering.

6. Overwintering larvae produced adults in early spring which matured and produced fertile eggs in as few as six days after emergence.

7. Overwintering larvae frequently add extra instars to the normal six. This mechanism is valuable to the species inasmuch as it extends development time.

8. Two species of parasites, *Apanteles militaris* and *Meteorus autographae,* were found to overwinter successfully as larvae in host armyworms.

9. The female moth was found to be capable of depositing a much larger number of eggs than was previously thought possible. One specimen deposited 1,759 eggs, all fertile and from only one mating.

10. Parasite-caused mortality of natural populations in Tennessee was 32.3 and 41.5 per cent, respectively, in 1956 and 1957.

11. The most important parasites of *P. unipuncta* in Tennessee are the braconid wasp, *Apanteles militaris* Walsh and the tachinid fly, *Winthemia rufopicta* Big.

12. A polyhedral virus disease takes a heavy toll of armyworms in Tennessee and is known to have been present in the state for three successive years, 1955-57.

13. A mass-rearing technique was developed from which as many as twenty thousand eggs were obtained from one cage of fifty moths in one week.

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SOME CLIMATIC RELATIONS OF ARMYWORM OUTBREAKS

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The sudden appearance and destructive outbreak of armyworms in 1953 raised the question, "Would it be possible to get some advance information in the future as to probable outbreaks?" To answer this question a study was made of weather conditions which are among the important factors governing insect populations of hosts, and parasites, and their diseases. Riley (1883), for example, states, "It is a well established fact that all great armyworm years have been unusually wet, preceded by one or more exceptionally dry years; and the widespread appearance of the insect in 1875 formed no exception to the rule." In Minnesota, Luggar (1888) notes "The reasons for the sudden appearance of such multitudes of worms may be explained by the repeated observations made again and again in many places, viz., that armyworms may be expected after periods of dry summers."

Notable Droughts in the United States

If we had all the records, we would no doubt find that somewhere in the United States some localities suffer from drought and perhaps armyworm damage each year. From time to time, however, drought conditions become widespread and unparalleled in extent. In the same way, certain years witness notable outbreaks of armyworms over large areas, when they truly live up to their name of armyworms, and become very destructive.

If we make a list of these outbreaks and the widespread droughts where records are available, we find frequent agreement. The year 1860, for example, was a year of widespread drought and we find that a destructive and remarkable outbreak of armyworms occurred in 1861, that called forth many articles. This was the first year in which the armyworm was studied at all scientifically. The years 1894 and 1895 were also hot and dry. This period in turn was followed by the widespread outbreak of armyworms in the year 1896, both in the United States and Canada. It was on account of this outbreak that Professor Slingerland of Cornell published Bulletin 133 on the armyworm. Again extensive drought conditions prevailed in the United States and Canada in 1913 and again we had the notable outbreak of worms in 1914.

Important drought conditions prevailed from 1930 to 1936 that gave rise to the much publicized dust bowl area in the southern plain states. This was followed by important armyworm years in 1931, 1935, and 1937.

We do not have all the records of armyworm outbreaks in Tennessee, but severe droughts have occurred over the years, notably in 1874, 1881, 1901, 1902, 1907, 1913, 1925, 1930, 1936, 1944, 1952, and 1953. The 1952 drought lasted 76 days and the 1953 drought 105 days with only 1.56 inches of rain. The worst outbreaks of armyworms in the history of Tennessee were in 1953 and 1954, which stimulated the present studies for basic information on the biology of this important pest (Breeland, 1957).

The 1954 outbreak was about two weeks earlier than in 1953, but a protracted cold spell delayed growth of larvae and less damage resulted.

A study of precipitation records for a given area as reported by the weather bureau may be misleading. Reporting stations may be fifteen to fifty or one hundred miles apart. It is well known that local showers may vary in amount and distribution during the summer months even in a radius of only five or six miles (Beebe, 1952). For example, Beebe reported more than twice the number of rain days for Gadsden, Alabama, than were reported for Walnut Grove only 15 miles away. Thus, there must be many showers of which the observer is unaware. Often the total rainfall for a given month in a given locality may be near normal, yet drought conditions may prevail because the showers were not well distributed. We can thus account for an armyworm outbreak at the farm of Mr. Allen at Sweetwater, Tennessee in 1956, while surrounding farms were free of armyworms.

Relative Values of the Natural Enemies and Diseases

During an outbreak of armyworms, one often observes Tachina flies buzzing around, and the mature worms covered with eggs at the head end. Because these flies are so in evidence, they are usually considered of the first importance in stemming an outbreak of armyworms.

Another important parasite is *Apanteles militaris* (Walsh), the cocoons of which are frequently seen after the outbreak subsides. In the fall of 1954, of thirty worms collected in the field at Knoxville by Dozier, twenty-nine were parasitized by *A. militaris.* Such parasitized worms do not eat as much as healthy worms, and often give rise to over fifty adult parasites each. *A. militaris* is one of the primary factors in keeping *P. unipuncta* in check (see Breeland, page 51). The efficiency of *A. militaris* is limited, however, because it appears to have very exact temperatures and moisture requirements for survival, making it difficult to rear. A knowledge of its optimum requirements would be of great help in elucidating the cause of armyworm outbreaks.

During the dry years of 1955 and 1956, field-collected worms by Breeland showed no evidence of disease, but those collected in 1957 were as much as 97 percent diseased, cause by a virus. The spring of 1957 had several prolonged and unusual rainy periods in February and April, lasting from ten to nineteen days in succession. This condition apparently favored the development of disease.

Can We Predict Armyworm Outbreaks?

The fact that many of the notable outbreaks of armyworms followed dry weather conditions of the preceding year made it appear that we might be able to forecast the probabilities of outbreaks (Marcovitch, 1957). For such a prediction we must assume that dry weather is much more detrimental to the parasites than to the host.

Dry weather is also unfavorable to virus diseases. We can thus generalize and postulate that dry weather favors armyworm outbreaks. The situation becomes complicated, however, when we have an unusual wet spring that favors disease, as was the case in 1957. Even though parts of Tennessee were dry in 1956, the expected outbreak did not materialize in 1957, due probably to the presence of disease. (See Breeland, page 64).

Summary

The most important armyworm outbreak in the history of Tennessee occurred in 1953, causing a loss of over ten million dollars.

The prevailing drought conditions of 1952 and 1953 focused attention on the possible effects of weather conditions as a cause of armyworm outbreaks. Studies were made of the literature on all important outbreaks. A study was also made of weather conditions in years preceding notable armyworm outbreaks. In most cases, important and widespread outbreaks were preceded by notable and severe droughts.

The outbreaks may be accounted for by the relative scarcity of parasites and disease, both of which are adversely affected by drought.

Extreme moist conditions favor virus diseases as a check on armyworm outbreaks.

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