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Scope and Method of Study: Numerous articles and publications on the biology and the biological control of the European corn borer were read and analyzed. An attempt was made to bring out some of the major points on the biology of the borer and to correlate these with biological control methods used against the borer.

Findings and Conclusions: The corn borer is a pest of great economic importance, particularly in the Corn Belt. Bivoltinism predominates when the populations are at their highest level in the Corn Belt.

The insects Lydella stabulens grisescens and Macrocentrus gifuensis, both parasites of the borer, have exhibited an ability to assist in corn borer control. It has been shown that Bacillus thuringiensis and Beauveria bassiana, pathogenic microorganisms of the corn borer, can be used successfully in the control of the borer.

ADVISER'S APPROVAL R R Walton

THE BIOLOGY AND BIOLOGICAL CONTROL
OF THE EUROPEAN CORN BORER

By

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PREFACE

The author, having lived on a farm in eastern Nebraska where corn is the major crop, has realized for a number of years that the European corn borer is a serious pest. There has been an interest in the control of the borer since the realization that it is such a pest. This interest was further stimulated after reading information on the biological control of insects, the corn borer in particular.

The author wishes to express sincere appreciation to Dr. R. R. Walton, who served as the adviser on this report; to Dr. L. Herbert Bruneau, who was his major adviser during the past school year; to Dr. Robert C. Fite, the director of the Academic Year Institute at Oklahoma State University; and to the National Science Foundation, which financed his past year of schooling and made this report possible.

G. L. Z.

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CHAPTER I

INTRODUCTION

The European corn borer, after having been introduced into the United States in the early 1900's, has become an insect pest of great economic importance. The early studies in borer research were aimed at keeping the borer out of the Corn Belt and holding their populations at low densities. Control measures recommended were mainly cultural and mechanical in nature. With the spread of the borer into the Corn Belt, the control measures were changed to the use of insecticides, varietal resistance, and biological control. The primary control measure from the mid-1940's up to the present time has been the use of organic insecticides. This resulted from the effectiveness of DDT in holding down borer populations. With the realization that prolonged use of organic insecticides can be dangerous to man, the utilization of biological methods to control borer populations has again been emphasized.

This report deals with work done on the biology and biological control of the corn borer. It was not possible to cite all of the material present in these areas because of the extensive work which has been done on the borer. It is hoped that the references cited will give a fair account of the results in the above two areas.

CHAPTER II

BIOLOGY

The scientific name of the European corn borer is *Ostrina nubilalis* (Hubner). The name under which most of the literature is found on the corn borer is *Pyrausta nubilalis* (Hubner). Brindley and Dicke (1963) state that the borer was placed in the genus *Ostrina* by Marion in the late 1950's. The change has been accepted and adopted in recent literature. This insect belongs in the order Lepidoptera and the family Pyralidae. (Borror and De Long, 1964).

The borer is native to Europe and is found in most of Europe and also in certain parts of Asia. It was probably brought into the United States in 1908 or 1909 in shipments of broomcorn from Italy or Hungary. The presence of a multiple-generation (bivoltine) strain, found mainly in the eastern part of the United States, and a single-generation strain, found predominantly in the Great Lakes region, indicate that borers in this country did not develop from a single importation. The latter strain was discovered in the United States in 1917 near Boston, Massachusetts in a plot of sweet corn (Metcalf, Flint, and Metcalf, 1962).

According to Brindley and Dicke (1963) populations and crop damage, in the early infestation period, reached a peak between 1925 and 1927, particularly in Ontario. The spread westward and southward was gradual between 1927 and 1936. In subsequent years the movement of the insect, both west and south, was rapid. It reached the Prairie Provices of

Canada in 1949, and spread to the Rocky Mountains and Gulf States of Mississippi, Alabama, and Georgia by 1950. An all-time peak in population, which prevailed over much of the central Corn Belt, occurred in 1949. The populations leading to this peak in this area were predominantly bivoltine. Bivoltinism was sharply reduced in 1950, as was the overall population. The population recovered gradually in later years, with bivoltinism reaching levels of 80 to 90 per cent toward the latter part of the 1950-60 decade.

Voltinism and the factors associated with diapause, which occurs only in the full-grown larva, have been investigated in a wide range of environmental conditions. Many investigators have concluded that diapause is closely associated with climatic conditions.

Mutchmor and Beckel (1959) found that at 65 F, the percentage of larvae of the corn borer entering diapause increased from practically 0 to 95 as the photoperiod was increased from 0 to 9.5-14 hours of light per day, and decreased sharply to a minimum of 3 as photoperiod was increased to 16 or more hours of light per day. Rearing and studies on oxygen consumption revealed that, to be most effective, exposure to factors inducing diapause must begin before the second day of the final instar at 65 F. Exposure during any single instar but the last was not effective in inducing diapause.

Arbuthnot (1944) concludes that the single-generation strain is a result of recessive genetic characters. This conclusion stems from results of experiments conducted from 1937-1940 at New Haven, Connecticut. These experiments were conducted under controlled laboratory conditions. Larvae were collected from fields near New Haven for test insects from the Eastern States; and from Toledo, Ohio; Mount Clemens, Michigan; and Rochester, New York for test insects from the Lake States. The material from New Haven was found to represent a homozygous multiple generation strain and no evidence was obtained to indicate the occurrence of a single-generation strain in the locality. The Toledo material was heterozygous, a complex of multiple- and single-generation strains occurring together. A homozygous single-generation strain was isolated from the Toledo material, but attempts to isolate a homozygous multiple-generation strain were not successful. Some larvae went into diapause before pupation in every one of four successive generations of every pedigreed line that was selected in an attempt to produce a purely multiple-generation strain from this stock.

The adults or moths of the corn borer begin emerging in June and continue to come out in the Northern States until August. These moths have a wing expanse of about one inch and are strong fliers, moving about mainly at night. The adult female moths are a pale yellowish brown with irregular darker bands running in wavy lines across the wings whereas the male moths are distinctly darker, having wings heavily marked with olive brown. Each female deposits an average of from 500-600 eggs in groups of from 5-50 on the underside of the leaves of their food plants. The eggs hatch in about a week into larvae which are from 3/4-1 inch in length. The body of the larva is flesh colored with small, round, brown spots (Metcalf, Flint, and Metcalf, 1962).

The first food of the young larvae consists largely of the tender leaf tissues. The young larvae are attracted to a moist, rather compact location and can always be found down in the whorl of the plant and the layers of the leaf roll. In areas of severe infestation, leaf injury due to the feeding of young larvae becomes prominent before any other indication is seen (Huber, Neiswander, and Salter, 1928). It was noted that as the leaves of the plants became exposed and the larvae advanced in their development, the primary feeding point of the third- and fourth-instar larvae was connected with the sheath and midrib, whereas the primary stalk invasion was by the fifth-instar larvae. For the second generation, which is abroad when field corn is usually in the flowering and ear development stage, the primary points of establishment of first-instar larvae are at the ligule and behind the sheath on pollen accumulations and on young ear shoots (Brindley and Dicke, 1963).

The borer passes the winter in the form of a mature larva in the stems or ears of the food plants on which it has been feeding. In field corn the majority of borers pass through the winter in the stalks which remain in the field after picking. Chiang (1964) reported on a two year study conducted in southern Minnesota to determine the population changes of borers in storage cribs, and the importance of stored corn as a source of borer infestation. It was found that (1) there was a considerable movement and also some mortality among the borers within the cribs; (2) both events were more intense among borers at the lower levels within the cribs; (3) pupation took place earlier and also was more successful near the top of the crib; (4) with the snow fence type crib, for every one hundred overwintering borers, twenty-two moths found their way out of the crib while many moths were trapped within the crib; and (5) storage corn contributed at least 26 per cent of the moth populations in the field the next spring.

After passing through the winter in the larval stage, the borer constructs a cocoon in the spring and transforms into a smooth, brown pupal stage.

Through laboratory tests and field observations it has been determined that very cold winters are unfavorable for this insect.

Hanec (1960) reported that the ability of the corn borer to adapt to the winter conditions of the northern parts of the Corn Belt was dependent on (1) synchronization of its life cycle with the relatively short corn growing season and (2) its ability to survive low winter temperatures as a mature larva. Winter survival of mature larvae was found to be dependent on a prolonged period of cold "hardening" brought about by decreasing temperatures of late fall and early winter. Cold hardy winter larvae survived up to three months at -20 C. under dry chilling conditions.

In laboratory studies conducted in the U.S.S.R. (Lozina-Lozinskii, 1963), it was learned that in November and December, larvae of the corn borer attained their greatest resistance to cold, the extent of which was related to the environmental temperature. After the larvae were kept at 22 C., the percentage surviving a temperature of -78 C. was low, but larvae which had been adapted to 0 C. for three to six weeks survived. Larvae "hardened" at 0 C., chilled to a -78 C., and kept at 0 C. for one month were able to develop and turn into pupae and moths. There was little effect on the survival of larvae by keeping them at -78 C. for one to twenty-five days. Larvae "hardened" to 0 C. then placed at a temperature of -30 C. for thirty to sixty minutes and then cooled to a -196 C., retained their viability as long as thirty-five days at 22 C. After freezing at -196 C., live larvae exhibited weak motor reactions. The cells of various tissues retained their ability to form normal neutral red granules and to respire, and the heart, gut, and extremities retained their ability to contract.

The borer has been found feeding on more than two hundred kinds of plants. It attacks nearly all herbaceous plants large enough for the larvae to enter. In the North Central and Middle West, the borer feeds almost entirely on corn although some of the common weeds, vegetables, flowers, and field crops are often found to be infested when such plants are grown next to badly infested cornfields. In the New England area this insect feeds extensively on potatoes, beans, beets, celery, dahlias, asters, chrysanthemums, gladoli, and many weeds, as well as corn. It has caused complete loss of crops of early sweet corn and it was estimated to have caused a loss of 313,000,000 bushels of corn and a total damage of $349,000,000 in 1949 (Metcalf, Flint, and Metcalf, 1962).

There are a number of indications of the presence of the corn borer. One of the first indications would be in seeing the moths flying about, mainly at night. In areas where there is a fairly heavy population, these moths are quite numerous. One of the first indications of damage done by the first brood of borers would be the small holes chewed in the young leaves. Around the margins of these eaten areas would be the whitish excrement of the borer. In the later stages of this brood, one would see small holes in the stalk or in the thicker parts of the leaf. The presence of the borer later in the season is indicated by tassels broken or bending over. In very severely infested areas the stalks may also be broken and lodging will occur. Most of the stalk breakage will not occur until after a frost when most of the moisture has left the plant.

Numerous studies have been carried out attempting to determine the relationship between borer population and crop loss and also in attempting to determine the size of the borer population.

Chiang, Holdaway, Brindley, and Neiswander (1960) reported on studies conducted at Ankeny, Iowa; Waseca, Minnesota; and Wooster, Ohio, during 1953, 1954, and 1955 to analyze the relationship between midsummer and fall corn borer populations and their effect on corn yield. These relationships are affected by the interactions of a number of factors: (1) the proportion of the first brood that pupate in the summer, (2) the selection of fields and plants for egg deposition by the moths, and (3) the survival of the different developmental stages of the second-brood individuals. A summer population of a given size may give rise to fall populations many times larger, or only a fraction of the original size. Furthermore, fall populations of the same size may consist of very different proportions of the residual first-brood population and the second-brood population. The quantitative relationships between midsummer and fall populations are further complicated by the following factors: (1) differential egg deposition owing to plant development; the plants that were more attractive to moths for egg deposition during the first brood will be less so during the second brood, and vice versa, (2) nonattractiveness to the second-brood moths for egg deposition of the plants that are heavily infested with first-brood borers, and (3) decreased survival of the second-brood larvae on plants with heavy first-brood injury. This fact may have been the result of a lack of suitable feeding sites on such plants. The paradoxical relationship between borer population and yield as shown in some cases, e.g., the fewer borers on the plants the less the yield, or the more borers the greater the yield, is clarified on the basis of the foregoing analysis of the borer population dynamics. Based upon these analyses the conclusion is reached that while the fall population may be a reliable basis for estimating the borer population entering hibernation, the summer population is probably a more realistic index for estimating the loss of corn caused by borer infestation in the current year.

In field tests conducted in Iowa it was learned that the first-brood infestation of a borer-susceptible, single-cross field corn resulted in a greater yield reduction than did infestation by the second brood. Both cavities in the stalk and lesions in the leaves were a better index of damage than were larvae. A greater yield loss per unit of damage occurred in the late planting than in the early planting. A 2.3 per cent yield reduction per cavity occurred in the early planting in 1958 and a one per cent reduction in 1959. In the late planting in 1958 a 4.1 per cent yield loss per cavity occurred. A 1.4 per cent reduction per leaf lesion occurred in the early planting in 1958 and a 1.7 per cent reduction in the late planting. In the fall, cavities in both split and dissected stalks gave a better estimate of yield reduction than did larvae. Cavity counts in split stalks were as reliable in estimating damage as cavity counts in dissected stalks. Because splitting required about one-fourth the time required to dissect a stalk, this method was proposed for determining borer damage. The yield reduction per cavity in the fall in both 1958 and 1959 averaged between one and two per cent. When yield loss occurred, the reduction was caused by infestation either by the first or the second brood, or by both, without an additional effect owing to the interaction of infestation by both broods (Jarvis, Everett, Brindley, and Dicke, 1961).

According to Barlow, Wressell, and Driscoll (1963), the summer infestations of the corn borer estimated from light-trap catches and surveys of cornfields in Kent County, Ontario, suggested that the size of infestations was largely determined by three factors: (1) the number of females in the first flight, (2) average rainfall per day during the first flight, and (3) average daily temperature during the first flight. The first factor was apparently most important, rainfall had less effect, and the influence of temperature was evidently negligible. Estimated size of first-generation infestations increased by 3.7 individuals for every unit increase in the number of females trapped during the first flight, by 12.2 individuals for every 0.01 inch of rain which fell during the first flight, and by 1.3 individuals for every 1 F. increase in mean daily temperature during the first flight. The regression explained 94 per cent of the variation in estimated size of summer infestations of the corn borer between 1947 and 1961. A hyperbolic relationship was implied between the number of females in the first flight and the number of progeny per female in first-generation infestations.

CHAPTER III

BIOLOGICAL CONTROL

Introduction

Swan (1964) defines biological control as the use of predators, parasites, and disease organisms to control insect pests.

The first published work reporting the transport of insects for biological control (predatory ants in Yemen) appeared in 1775. In 1800 Erasmus Darwin, the father of Charles Darwin, suggested the possibility of biological control in a book on agriculture and gardening published in London. In the United States the first suggestion for importing insect enemies of a pest from its native country, in print at least, was in 1855 when Asa Fitch wrote to the president of the Royal Entomological Society in London requesting that parasites of the wheat midge be collected in Europe and shipped here. The first intentional introduction of a foreign parasite into the United States took place in 1883 when C. V. Riley imported *Apanteles glomeratus*, a parasite of the imported cabbage worm, from England. The first attempt in this country to control pests biologically over a wide area was undertaken in 1905 by the United States Department of Agriculture, in cooperation with the Commonwealth of Massachusetts, against the gypsy moth and the Browntail moth. The most successful biological control project in entomological history was the control of the cottony cushion scale, in California, by the vedalia beetle. It was from the great success of this project that other biological control programs were carried out with such great enthusiasm (Swan, 1964).

With the discovery of the European corn borer in the United States in 1917, a major biological control program was set in motion. Although the United States program of large scale importation ended in 1938, a few species were imported from Europe up to about 1950 (Clausen, 1956).

During the years of 1919-1940, over 23 million borer larvae from Europe and 3 million from the Orient were shipped to the United States for rearing the natural enemies that were present in the larvae. Many other natural enemies or parasites were sent over in cocoon or pupal stages. There was a total of twenty-four species of parasites brought in by these importations and of these, twenty-two species were sufficiently numerous to permit extensive colonization over the borer infested area in this country. The adult parasites were released at selected localities over the entire infested area where the borer was sufficiently abundant to support a parasite population. Field surveys were maintained at these points to determine the species that became established and also to determine the biological and environmental requirements needed to increase their distribution within the colonized areas and in colonizing newly infested areas as the corn borers spread. It was found that six of the twenty-two species became permanently established: *Lydella stabulens grisescens* Robineau-Desvoidy, *Horogenes punctorius* (Roman), *Macrocentrus gifuensis* Ashmead, *Eulophus viridulus* Thomson, *Chelonus annulipes* Wesmael, and *Phaeogenes nigridens* Wesmael (Baker, Bradley, and Clark, 1949).

The first written reference to disease in insects was by Aristotle, who observed certain abnormalities among bees that are almost certainly the familiar disease found in bee colonies today. Other early writings dealt with abnormalities in silkworms (Swan, 1964).

Three microorganisms have been found to be fairly effective in the control of the corn borer. These microorganisms are *Bacillus thuringiensis* Berliner, *Perezia pyraustae* Paillot, and *Beauveria bassiana* (Balsamo) Vuillemin.

Imported Parasitic Insects

Lydella stabulens grisescens Robineau-Desvoidy

Lydella stabulens grisescens R. D. belongs to the order Diptera and to the family Tachinidae (Borror and De Long, 1964).

This species has been the most successful of the imported parasites in the control of the European corn borer. It is common in Europe and the Far East as an enemy of the borer and is found as a solitary internal parasite of the host larva, preferring the fourth-instar larva. Two generations of parasites are produced annually, the second generation overwintering as young larvae in the body of the host. The reproductive capacity of this tachinid fly is fairly high, each female developing, on the average, about 350 eggs. The female fly is attracted by the odor of the excrement or possibly by the odor of the host itself to the borers tunnel. The female deposits an average of two larvae and two eggs, with each deposition, in the frass and excrement of the borer at the entrance to the borers tunnel. The eggs rarely hatch after leaving the ovipositor. The larva deposited at the burrow opening seeks out the host and enters it through a body opening or by puncturing the skin with its mandibles. Once inside the host, it seeks the main tracheal trunk of the breathing apparatus, cuts one of these, and forms a collecting tunnel to supply itself with oxygen during its development. During the first and second instars the larva feeds almost entirely on the body fluids of the host and does not injure the fatty lobes and internal organs. The third-instar larva feeds on the fatty tissue, and just before issuing, consumes most of the internal organs. Immediately upon the death of the host, the parasite leaves by puncturing the skin of the host and proceeds to spin a cocoon (Baker, Bradley, and Clark, 1949).

Material for colonization of this species has been imported from both Europe and the Orient. This tachinid fly was among the first parasites of the corn borer to be imported, a small colony of 70 adults having been released at Watertown, Massachusetts, in 1920. Since then it has been more widely colonized than any other of the introduced parasites. All of the earlier colonies were located in New England, and a considerable number of the earliest, consisting of European stock, in northeastern Massachusetts. By 1930 parasitization in this locality had increased to the point where it was feasible to collect for further distribution. During the seven-year period of 1930 to 1937, over 14,000 adults were taken from eastern Massachusetts for colonization elsewhere. This parasite was first introduced into the Lake States area in 1927 where it showed good initial establishment on the single-generation strain of the borer. Surveys conducted at the close of the 1938 season and including the years from 1932 through 1938 give the following results: Parasitization of the borer by the tachinid fly within 3.5 miles of the release point was 0.3 per cent in 1932; 1933, 2.8 per cent; 1934, 6.3 per cent; 1935, 7.6 per cent; 1936, 10.0 per cent; 1937, 17.1 per cent; and 1938, 20.9 per cent. The above survey was conducted in Jerusalem Township, Lucas County, Ohio. A total of 702,037 adult parasites were released in the United States from 1920-1940 (Baker, Bradley, and Clark, 1949).

This parasite is well established in Massachusetts, Connecticut, and Rhode Island where parasitization ranges from 16-45 per cent. It has been extensively colonized in the North Central states since 1944 with the result that it is widely established in that area also. Field parasitization in Illinois, Indiana, and Iowa has ranged from 45-75 per cent (Swan, 1964).

The state of Iowa released 54,751 adult forms of this parasite from 1944-1951. It is widely established in the eastern half of the state and the percentages of borers parasitized by this species in some areas of eastern Iowa in 1948 and 1949 exceeded that reported in European areas (Blickenstaff, Arbuthnot, and Harris, 1952).

A total of 14,517 Lydella stabulens grisescens was released in Illinois from 1943-1947. It was the most successful of the parasites released. It has been established in numerous areas in the northern part of the state where parasitization equaled that reported in Europe (Arbuthnot and Wright, 1951).

Lydella stabulens grisescens was released in Delaware in June, 1959. Prior to these releases parasitism of the borer was practically non-existent. A total of 2,933 adult parasites was released in six areas of the state. In the fall of 1959 and the winter of 1960 a total of 88 fields were sampled and 4,249 borers were collected for parasite emergence. L. stabulens grisescens was the only parasite recovered in any abundance. It was recovered from 16 of the 88 fields sampled. Parasitism in these fields ranged from 2.1 per cent to 7.7 per cent, with a mean of 3.45 per cent. Dispersal occurred in at least two different directions in every positive sampling area with one exception, where dispersal was northward only. Maximum distance of dispersal was at least 2 miles (Van Denburgh, Burbutis, and York, 1962).

Macrocentrus gifuensis Ashmead

The insect Macrocentrus gifuensis belongs to the order Hymenoptera and the family Braconidae (Borror and De Long, 1964).

It is common in Europe and is also important in Japan in controlling the borer. This insect overwinters as an embryo in mature borer larvae. Each egg develops into 8 or 10 larvae which appear in April. This type of development is called polyembryony. The first-stage larvae feed mostly upon the fat globules of the host larvae. The second- and third-stage larvae feed internally but the fourth stage emerges from the host and feeds externally. Pupation takes place about the middle of June and adult emergence towards the latter part of June. Shortly after emerging, the adult females will start ovipositing. Usually one egg is deposited by the female with each thrust, however, two or three eggs may be found in each larva because of the repeated thrusts that this wasp makes. The time required to complete development from early spring to the adult stage is 34 days at 25 C. and 54 days at 20 C. (Parker, 1931).

The orginal supply of this polyembryonic braconid parasite for release in the United States was obtained from Europe and the Orient. The first adults of European origin became available for release in 1926 and were liberated in Massachusetts. In 1927 a number of colonies were released in the East and a colony of European origin was also released at Jerusalem Township, Lucas County, Ohio. A number of colonies of European material were released annually in both the Eastern and the Lake States from 1927-1933. In 1929 the first adults were obtained from the Orient, and material from this source continued to be received during the following three years. During the years of 1926-1940, a total of 421,031 adult parasites were released in the United States (Baker, Bradley, and Clark, 1949).

Macrocentrus gifuensis was first recovered in the East in 1934 at Bridgewater, Massachusetts. In the fall of 1936 and 1937 it was obtained from a number of fields in the Bridgewater district. In 1937 thirty-three per cent of the borers in one collection were parsitized by this wasp. A survey of the first-generation borers in 1938 showed an average parasitization by *Macrocentrus gifuensis* of 3.9 per cent in a circular area containing 490 square miles, and in two of the collections over 35 per cent of the borers were parasitized. In the fall of that year, in a circular area of 1,963 square miles, 8 per cent of the borers were parasitized by *M. gifuensis*. In the central 500 square-mile portion of this area parasitization had increased to an average of 10.8 per cent. In 1939 a survey of a 500 square-mile area revealed parasitization by *M. gifuensis* to be 12.1 per cent. This was the highest recorded for any parasite and comprised 46 per cent of the total by all species (Baker, Bradley, and Clark, 1949).

A total of 732,139 adult parasites were released in Iowa from 1944-1951. The only area where it persisted or showed evidence of permanent establishment was in the northern half of the state. This species has not demonstrated that it can survive in the state of Iowa (Blickenstaff, Arbuthnot, and Harris, 1952).

The state of Illinois released 183,367 adult parasites from 1942-1949. There has been no evidence that this parasite has survived beyond the year of release (Arbuthnot and Wright, 1951).

Horogenes punctorius (Roman)

Horogenes punctorius is a wasp belonging to the order Hymenoptera and the family Ichneumonidae (Borror and De Long, 1964).

It is common in the warmer sections of Europe and in the colder regions of the Orient. It is an internal parasite of the borer larva, preferring the second-, third-, and fourth-instar larva. This ichneumonid produces one or two generations per year, depending upon the seasonal cycle of the host. Parasitization by Horogenes punctorius retards the growth of the host, even though the parasite larva remains in the first instar throughout the normal feeding period of the host and grows very slowly. This parasite overwinters as a first-instar larva within the mature host larva. After the first-instar the parasite larva develops rapidly, spending but a few days in the second and third instars. This wasp usually consumes all but the head capsule and the shriveled larval skin by the time it has finished feeding. The adults of this parasite usually emerge in late June and early July at which time the females oviposit their eggs in the body cavities of the host larvae (Baker, Bradley, and Clark, 1949).

Horogenes punctorius was also one of the first parasites to appear in the earlier importations from Europe, a colony of ten adults having been released in 1921 at Malden, Massachusetts. In 1930 the first releases of adults originating from the Orient were made. Colonization of *Horogenes punctorius* in the Lake States area was started in Monroe County, Michigan, in 1926 with a release of 207 adults. A total of 139,185 parasites was released in the United States from 1921-1940. Parasitization has been as high as 50 per cent in the eastern part of the United States although it has not persisted at this high level. Initial establishment was readily obtained following releases in both the eastern and middle-western areas, but maintenance of the species is evidenced only in the eastern area (Baker, Bradley, and Clark, 1949).

The state of Illinois released a total of 5,273 adults of this parasite from 1942-1947. Collections made at the ends of the growing seasons showed no recovery of this parasite indicating that survival did not persist after the year of release (Arbuthnot and Wright, 1951).

During the years of 1944-1951 the state of Iowa released 17,166 of these parasites. Most of the releases were in the eastern counties. Permanent establishment occurred in a few localities where the parasitization was fairly low (Blickenstaff, Arbuthnot, and Harris, 1952).

Sympiesis viridula Thomson

This insect is referred to in earlier writings as *Eulophus viridulus* Thomson.

Sympiesis viridula is a wasp belonging to the order Hymenoptera and the family Chalcididae (Borror and De Long, 1964).

This chalcid wasp is an external parasite of the borrer larva, preferring the mature larva but also attacking the third- and fourth-instar larva. The female wasp stings and completely paralyzes the larva before ovipositing. The eggs are placed more or less indiscriminately on the host. The young larvae wander little, if any, from the hatching points, but start their external feeding at once. They grow rapidly and within 4 to 5 days reduce the host to an empty skin. They then disperse, some crawling away to a distance of 2 or more inches, and pupate. Winter is passed in the pupal stage in the host tunnels (Parker and Smith, 1933).

This chalcid wasp was imported from Italy. The first releases in the United States were made in 1930, when four small colonies were liberated, three in Massachusetts and one in Rhode Island. Introductions and releases were made during the following 4 years in the Eastern and Lake States. The total number of adult parasites released in the United States from 1930-1940 was 317,543. The first recovery of this wasp was made in 1931 at three release points in the Lake States region. It first appeared on a maintenance basis in 1938 in the Lake States. Parasitization has reached 15 per cent in a few localities (Baker, Bradley, and Clark, 1949).

During the years from 1945-1948 the state of Iowa released 18,486 adult chalcid wasps in a total of 8 counties, most of them being in the eastern part of the state. It was found that parasitization was fairly low and that there was an extensive dispersion of this wasp without a great abundance of population in any one locality (Blickenstaff, Arbuthnot, and Harris, 1952).

Two releases of 2,961 individuals, in 1946, in the state of Illinois also resulted in a wide distribution of the parasite with low parasitization (Arbuthnot and Wright, 1951).

Phaeogenes nigridens Wesmael

Phaeogenes nigridens is a wasp belonging to the family Ichneumonidae of the order Hymenoptera (Borror and De Long, 1964).

This insect is common as a parasite of the borer in Europe. It is an internal solitary parasite of the borer pupae, preferring one- and two-day old pupae. The adult female enters the borers tunnel, finds a pupa, chews a hole through the cocoon and then oviposits. Usually only one egg is deposited in each pupa. The egg of *Phaeogenes* floats freely in the body of the pupa. The incubation period of the egg at 25 C. is about two days, and at 18 C. is four days. The food of the first- and second-instar larvae is mainly the blood and fat of the host. In the third stage, however, the larva attacks the vital organs and some of the integumentary muscles, in fact, almost everything except the large tracheal branches. A total of six days is spent in the larval stage when kept at a temperature of 25 C. The pupa is formed within the borers pupa and after about four days in the pupal stage the wasp emerges. This insect hibernates as an adult in sheltered areas. (Smith, 1932).

Phaeogenes nigridens was imported from Europe and Japan and the first release in the United States was made in 1924, when a small colony was liberated at Arlington, Massachusetts. Releases in the Lake States began in 1926. The total number of adult parasites of this species released in the United States from 1924-1940 was 52,734. The first recovery of this parasite was made in 1925 at Arlington, Massachusetts, following large releases made that year. The parasite was taken at three locations in eastern Massachusetts in 1926 and 1927. In 1929 adults of P. nigridens emerged from cornstalks heavily infested with the corn borer obtained at one of the locations in eastern Massachusetts, and from pupae collected during the summer at the same point. These recoveries showed maintenance of the species for a period of three years in the absence of supporting releases at this point. Initial establishment of the species was noted in 1938 at a location in New Jersey. Parasitization by this ichneumonid wasp has benerally been low (Baker, Bradley, and Clark, 1949).

The state of Iowa released 500 adult parasites in the summer of 1945 in one eastern county. This wasp had not been recovered in Iowa up to 1950 (Blickenstaff, Arbuthnot, and Harris, 1952).

Chelonus annulipes Wesmael

Chelonus annulipes is a parasitic wasp belonging to the family Braconidae of the order Hymenoptera (Borror and DeLong, 1964).

This insect is the only imported parasite that attacks the host in the egg stage. The female usually deposits one egg in each host egg. During the first three larval stages, this braconid is found within the growing larva of the host. During its last stage the parasite larva issues from the fourth-instar Pyrausta, devours all remaining contents of the latter, spins a cocoon, and pupates. Under field conditions it is probable that the egg-to-adult period covers about 40 days (Vance, 1932).

Chelonus annulipes was imported from the northern part of Italy in 1929 in the pupal stage and the first colonization in the United States took place in the Lake States area in 1930. Colonization also took place in the Eastern States in 1932, along the eastern shore of Virginia in 1937, and again in the Lake States region in 1938 and 1939. The releases in the Great Lakes area in 1938 and 1939 were to test the effects of the bivoltine strain of borer on this parasite. A total of 279,930 adults were released in the United States from 1930-1940 (Baker, Bradley, and Clark, 1949).

From observations and field collections it was learned that Chelonus annulipes is a parasite that can exist only in a more or less restricted ecological island, producing effective parasitization in the central portion and diminishing in numbers as the less favorable periphery is approached. As a result of the above information, it was proposed to release this parasite in heavily infested areas in colonies very closely spaced together. Two areas were selected, one in Connecticut and the other in the New York City area. In the area selected for colonization in Connecticut, forty-eight colonies averaging about 1,000 adults per colony and spaced about four miles apart, were released in 1939. Twenty-three colonies of similar size were released that year in the Hudson River Valley. The releases made in the Hudson River Valley were too late to be effective. There were not enough of the hosts eggs present at the time of release. The lower Hudson River Valley was recolonized in 1940 when 110 colonies, totaling 109,213 adults of Chelonus annulipes, were released. An excellent synchronization of parasite releases with presence of host eggs was attained with these releases. Field parasitization by Chelonus annulipes was

13.0, 15.2, and 24.0 per cent in three field collections made in 1937 near Dighton, Massachusetts. The last surveys made in the East showed this braconid to be on a maintenance basis at only one locality, namely, that around Taunton, Massachusetts. The releases made in the Great Lakes area, to check on the effect of a bivoltine strain of host on the parasite, showed an increase in the numbers of the parasites a year later. However, the parasite failed to appear in the collections made in 1940 (Baker, Bradley, and Clark, 1949).

A total of 16,460 adults of this species was released in Iowa from 1944-1951. These releases were made at 11 localities, mainly in the eastern part of the state. This wasp is not known to be established in Iowa (Blickenstaff, Arbuthnot, and Harris, 1952).

The state of Illinois released 4,355 of these parasites from 1944-1946. A recovery of this wasp was made in 1944 but none occurred in later years. There has been no evidence that this parasite has become established in Illinois (Arbuthnot and Wright, 1951).

Disease microorganisms

Bacillus thuringiensis Berliner

Probably the most studied, most frequently investigated and reported microorganism associated with disease in insects is the bacterium, Bacillus thuringiensis. This bacterium primarily attacks members of the order Lepidoptera and was first reported by E. Berliner in 1911, when he isolated it from diseased larvae of the Mediterranean flour moth. In the late 1920's and early 1930's there appeared a number of papers on the effectiveness of B. thuringiensis as an agent for the biological control of the European corn borer. Work with this organism came to a stop early in the 1930's because of a lack of enough information on the factors governing what may be called the virulence of the bacterium. In 1951 E. A. Steinhaus reawakened interest in the potentialities of this bacterium as an insect pathogen (Steinhaus, 1963).

This microorganism can be cultured on ordinary nutrient agar without losing any of its virulence. The toxicity brought about in insects is caused by "inclusions" which are crystal-like bodies formed during sporulation. This pathogen was approved in 1960 as an "insecticide" with exemption from any requirement of tolerance. It is a microbial insecticide, being sold under brand names such as Bakthane, Biotrol, Parasporin, and Thuricide (Steinhaus, 1963).

Field tests at Ankeny, Iowa, were conducted to determine the effect of B. thuringiensis on the corn borer. The applications of this bacterium were on granular carriers. Formulations of 2, 10, and 50 grams of Bacillus per pound of corn meal gave 46, 63, and 85 per cent reduction of the first brood. Two applications of 20 pounds of corn meal per acre with 50 grams of Bacillus per pound gave 77 per cent control of the second brood (York, 1958).

In 1959 Bacillus thuringiensis Berliner (25×10^9 spores per gram) at 2 and 4 pounds of wettable powder per acre was compared with: DDT, $1\frac{1}{2}$ pounds; Sevin, 2 pounds; heptachlor, 1.25 pounds; Dylox, 2 pounds; and Kepone, 1 pound. In 1960 two additional preparations, one (30×10^9 spores per gram) at 2 pounds per acre, the other (75×10^9 spores per gram) at 2 and 4 pounds, 2 pounds plus half dosage of DDT, and 2 pounds plus half dosage of Sevin were compared with DDT, Dylox, and

Kepone at the 1959 dosages, and Seven at 1.2 pounds per acre for the control of the European corn borer on sweet corn in southwestern Quebec, Each year, in early July, two applications were made at a week interval with a commercial sprayer. Per cent infested plants and ears and numbers of borers in the plants and ears were obtained by dissecting at harvest 25 corn plants per replicate per treatment. In 1959, plots treated with DDT or Sevin gave more than 91 per cent marketable ears, heptachlor, 84 per cent; Kepone, Dylox, B. thuringiensis at 2 and 4 pounds, 72 to 77 per cent. In 1960, DDT, Sevin, Dylox, Kepone, Thuricide (30×10^9 spores per gram), B. thuringiensis at 4 pounds, and the bacillus plus DDT or Sevin gave more than 95 per cent marketable ears; B. thuringiensis at 2 pounds, 88.5 per cent. In 1959, only 58 per cent of the ears in the untreated plots were marketable; in 1960, 88 per cent. The percentage of untreated plants damaged in 1959 was 68; in 1960, 24. B. thuringiensis at 2 and 4 pounds per acre under heavy corn borer infestation was inferior to the standard DDT emulsions sprays and did not give adequate control. The results of this two-year study indicate that susceptibility of the European corn borer to B. thuringiensis is rather low and inconsistant, and under heavy infestations, a relatively high dosage is required for satisfactory control (Hudon, 1962).

According to Raun (1963) a test conducted at Ankeny, Iowa, showed that fourth- and fifth-instar larvae of the corn borer ceased feeding within 50 minutes and died in 24 to 72 hours after eating food treated with Bacillus thuringiensis, without showing signs of total paralysis. Commercial granular formulations of the crystalliferous bacterium controlled first-brood field infestations of the borer as effectively as did recommended insecticides, but failed to satisfactorily control the second-brood. Spray formulations did not give satisfactory results.

Perezia pyraustae Paillot

Perezia pyraustae is a protozoan belonging to the order Sporoza. It was first established by E. A. Steinhaus in 1951 that the corn borer is subject to a disease caused by this microorganism. This pathogen is transmitted by the ingestion of contaminated food. It causes a swelling and destruction of the Malpighian tubules, these structures turning an opaque white. It was found that all stages of the borer are subject to attack (Swan, 1964).

In a study of the disease begun by the Illinois Natural History Survey, investigations made in twenty-three counties of the state from 1954 through 1957 showed that 52 per cent of the corn borer larvae entering hibernation in the fall were infected with this pathogen. Prior to the period of pupation in the spring, the average incidence of infection in that segment of the population which survived was only 19 per cent over a two-year average. For the same period, the average incidence of *P. pyraustae* among individuals which perished during the rigors of winter was 91 per cent. Hence, mortality resulting from the stress of winter was greater in that segment of the population which was infected. Another reduction in the infected segment of the population which was also associated with weather conditions was observed following a period of unseasonably hot spring weather. The incidence of *Perezia* among dead pupae observed was 98 per cent while only 13 per cent of the living pupae were so infected. Hence, infected borers appear to be more sensitive to high temperatures than their disease-free counterparts (Kramer, 1959a).

Kramer (1959b) also showed that this pathogen can be transmitted in borers from the mother to her offspring. There was a marked difference in rate of survival between transovarially infected versus disease-free borers. Among the former about 14 per cent reached adulthood while among the latter 75 per cent reached maturity. It was also shown that the egg production in diseased-adult females was reduced, occasionally to zero.

Zimmack and Brindley (1957) reported on a study conducted in Iowa testing the effect of Perezia pyraustae on the corn borer. Of a total of 360 first-instar larvae reared on uncontaminated synthetic food medium, a total of 56 per cent developed as compared with 77 per cent that were uninfected by the parasite. Infected moths averaged three days shorter life and produced an average of 39 less eggs than uninfected moths. Egg production and longevity data on copulating moths showed the Perezia-infested individuals, compared with uninfected moths, averaged three days shorter life, nine fewer egg masses, and 47 per cent fewer eggs.

A survey conducted in Delaware showed a high incidence of Perezia pyraustae in European corn borer larvae collected in the fall of 1959. Four hundred additional larvae were collected in April, 1960, and subjected to controlled laboratory studies of the host-parasite relationship. Of the 114 adults that emerged from these larvae, P. pyraustae was found in 85 per cent. Eighty per cent of a sample of 50 dead larvae examined contained spores of this pathogen. P. pyraustae significantly reduced adult longevity in both males and females. The fecundity of infected females was greatly lowered as compared with noninfected females. The number of viable eggs laid by infected females was somewhat lower, suggesting that the pathogen may also have adversely influenced embryonic development. The results of these investigations, coupled with recent findings of workers in other areas of the country, suggest the P. pyraustae may be an important biotic factor in the regulation of the population density of the European corn borer in Delaware (Van Denburgh and Burbutis, 1962).

Very little has been done by way of artificial distribution of the microsporidian spores for biological control, presumably because this pathogen can not be cultured on artificial media, but from the information now available on this pathogen, it should be considered as an important factor in supressing corn borer populations.

Beauveria bassiana (Balsamo) Vuillemin

Beauveria bassiana, an imperfect fungus, is another disease-causing organism that affects the European corn borer. This fungus enters the insect through the integument not more than two days after the conidia have become attached to the skin. Warm temperature and high humidity cause germination of the spores and the mycelia then penetrate the integument. The fungus can also enter the insect through the alimentary tract. Shortly after the mycelia have penetrated the insects body, short hyphal strands are formed in the blood which consume the blood cells. The solid tissues are not attacked until after the insect dies and the body then takes on a reddish color. When moist, the white mycelia can be seen in the insect. After a short time in a moist atmosphere, great numbers of conidia develop giving the body a powdery appearance. This fungus can be grown on almost any artificial media and will retain its virulence for long periods of time when kept on the media or as pure spores at temperatures near or below freezing (Steinhaus, 1963).

In field tests conducted at Ankeny, Iowa, in 1955, 1956, and 1957, *Beauveria* was applied to corn plants in water sprays, in flour, and on granular carriers. In 1955 the average reduction of first-brood larvae in four tests using sterilized corn meal as a carrier for the *Beauveria* spores was 88 per cent, while attapulgite granules in the same tests gave 78 per cent reduction. Maximum reduction of the second brood population was 42 per cent. In first brood timing experiments in 1956 the highest mortality of 90 per cent was obtained on the last date of application of June 29. In the 1957 timing experiment with *Beauveria* for the first brood, best results were obtained on June 25, with nearly equal results on June 20 and June 30. In an experiment on 12 and 20 pound rates per acre using three grams of spores per pound, there was no appreciable difference in control. The reduction was from 60 to 70 per cent. Best results in the second brood timing experiment were obtained from the first and second applications. Although the reductions were in the 50-60 per cent range, they were comparable to insecticides (York, 1958).

Field and laboratory tests were carried out in Iowa in 1959 and 1960. These tests showed that all moths treated with *Beauveria bassiana* died within five days. In a first brood timing experiment in 1959, a reduction of 87.5 per cent in the number of larvae was obtained with a granular formulation of Beauveria applied on June 25. Nearly equal results were obtained with a spray formulation applied on June 19. In a timing experiment for control of second brood larvae in 1959, a reduction of 72.8 per cent was obtained with the spray formulation and 59.1 per cent with the granular formulation when applied on August 18. Single, double, and triple applications of spray and granular formulations were made by hand for control of first brood larvae in 1960. A reduction of 100 per cent was obtained in the plots receiving the three applications of the granular formulation (Smith, 1961).

CHAPTER IV

SUMMARY

Numerous articles and publications on the biology and biological control of the European corn borer were read and analyzed. An attempt was made to bring out some of the major points on the biology of the borer and the biological control methods used to help hold the borer populations down.

It was determined that:

(1) The European corn borer is an insect pest of great economic importance occurring in the United States from the Eastern States to the Rocky Mountains. The greatest amount of damage is done in the Corn Belt where it feeds principally upon the corn plant.

(2) The borer populations in the Corn Belt are found to be principally bivoltine when the over-all populations are at a peak. The damage done by the first-brood generation is slightly greater than that done by the second-brood generation.

(3) The ability of the borer larvae to survive cold winters is brought about by a gradual decrease in the temperatures in fall and early winter.

(4) *Lydella stabulens grisescens* and *Macrocentrus gifuensis*, imported parasitic insects of the corn borer, are sufficiently

established and their parasitization upon the borer in certain areas has a definite effect upon controlling the borer populations.

(5) *Bacillus thuringiensis* and *Beauveria bassiana*, microorganisms causing disease in the borer, have achieved good degrees of borer control.

LITERATURE CITED

Arbuthnot, K. D. 1944. Strains of the European corn borer in the United States. U. S. Dept. Agr. Tech. Bull. No. 869, 20 pp.

_______, and J. M. Wright. 1951. Parasites of the European corn borer in Illinois. Trans. Illinois State Acad. Sci. 44:222-234

Baker, W. A., W. G. Bradley, and C. A. Clark. 1949. Biological control of the European corn borer in the United States. U. S. Dept. Agr. Tech. Bull. No. 983, 185 pp.

Barlow, C. A., H. B. Wressell, and G. R. Driscoll. 1963. Some factors determining the size of infestations of the European corn borer, Ostrina nubilalis (Hbn.) (Pyralidae:Lepidoptera). Can. J. Zool. 41(6):963-970.

Blickenstaff, C. C., K. D. Arbuthnot, and H. M. Harris. 1952. Parasites of the European corn borer in Iowa. Iowa State Coll. J. Sci. 27:335-379.

Borror, D. J., and D. M. De Long. 1964. An Introduction to the Study of Insects. Rev. ed. Holt, Rienhart and Winston, Inc., New York.

Brindley, T. A., and F. F. Dicke. 1963. Significant developments in European corn borer research. Ann. Rev. Entomol. 8:115-176.

Chiang, H. C. 1964. Overwintering corn borer, Ostrinia nubilalis, larvae in storage cribs. J. Econ. Entomol. 57(5):666-669.

_______, F. G. Holdaway, T. A. Brindley, and C. R. Neiswander. 1960. European corn borer populations in relation to the estimation of crop loss. J. Econ. Entomol. 53(4):517-522.

Clausen, C. P. 1956. Biological control of insect pests in the United States. U. S. Dept. Agr. Tech. Bull. No. 1139, 151 pp.

Hanec, W. 1960. Adaptations of the European corn borer, Pyrausta nubilalis (Hubn.) for winter survival. Dissertation Absts. 20(10):3908-3909.

Huber, L. L., C. R. Neiswander, and R. M. Salter. 1928. The European corn borer and its environmant. Ohio Agr. Expt. Sta. Bul. No. 429, 196 pp.

Hudon, M. 1962. Field experiments with Bacillus thuringiensis and chemical insecticides for the control of the European corn borer, Ostrinia nubilalis, on sweet corn in southwestern Quebec. J. Econ. Entomol. 55(1):115-117.

Jarvis, J. L., T. R. Everett, T. A. Brindley, and F. F. Dicke. 1961. Evaluating the effect of European corn borer populations on corn yield. Iowa State J. Sci. 36(2):115-132.

Kramer, J. P. 1959a. Observations on the seasonal incidence of microsporidiosis in European corn borer populations in Illinois. Entomophaga 4(1):37-42.

_______. 1959b. Some relationships between Perezia pyraustae Paillot (Sporozoa, Nosematidae) and Pyrausta nubilalis (Hubner) (Lepidoptera, Pyralidae). J. Insect Pathol. 1:25-33.

Lozina-Lozinskii, L. K. 1963. Reaktsiya nasekonykh na glubodoe okhlazhdenie. (Reactions of insects to penetrating cold.) SB RABOT INST TSITOL AKAD NAUK SSSR 4:34-53. (English summ.) Referat. Zhur., Biol., 1963. No. 24E176.

Metcalf, C. L., W. P. Flint, and R. L. Metcalf. 1962. Destructive and Useful Insects. 4th ed. McGraw-Hill Book Co., New York.

Mutchmor, J. A., and W. E. Beckel. 1959. Some factors affecting diapause in the European corn borer, Ostrinia nubilalis (Hbn.). Can. J. Zool. 37:161-168.

Parker, H. L. 1931. Macrocentrus gifuensis Ashmead, a polyembryonic braconid parasite in the European corn borer. U. S. Dept. Agr. Tech. Bull. No. 230, 63 pp.

_______, and H. D. Smith. 1933. Eulophus viridulus Thoms., a parasite of Pyrausta nubilalis Hubn. Ann. Ent. Soc. Amer. 26:21-37.

Raun, E. S. 1963. Corn borer control with Bacillus thuringiensis Berliner. Iowa State J. Sci. 38(2):141-150.

Smith, H. D. 1932. Phaeogenes nigridens Wesmael, an important ichneumonid parasite of the pupa of the European corn borer. U. S. Dept. Agr. Tech. Bull. No. 331, 46 pp.

Smith, O. E. 1961. Control of the European corn borer with the fungi, Metarrhizium anisopliae and Beauveria bassiana. Dissertation Absts. 22(2):686.

Steinhaus, E. A. 1963. Insect Pathology. Vol. 2. Academic Press Inc., New York.

Swan, L. A. 1964. Beneficial Insects. Harper and Row. New York.

Vance, A. M. 1932. The biology and morphology of the braconid Chelonus anulipes Wesm., a parasite of the European corn borer. U. S. Dept. Agr. Tech. Bull. No. 294, 48 pp.

Van Denburgh, R. S., and P. P. Burbutis. 1962. The host-parasite relationship of the European corn borer, Ostrinia nubilalis, and the protozoan, Perezia pyraustae, in Delaware. J. Econ. Entomol. 55(1):65-67.

________, ________, and G. T. York. 1962. The re-introduction and recovery of Lydella stabulens grisescens, a parasite of the European corn borer in Delaware. J. Econ. Entomol. 55(1):11-14.

York, G. T. 1958. Control of the European corn borer with the fungus Beauveria bassiana and the bacterium Bacillus thuringiensis. Dissertation Absts. 19(3):397-398.

Zimmack, H. L., and T. A. Brindley. 1957. The effect of the protozoan parasite, Perezia pyraustae Paillot, on the European corn borer, Pyrausta Nubilalis (Hubner). J. Econ. Entomol. 50(5):637-640.

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