PRESIDENTIAL ADDRESS

By H. F. Willard

(Presented at the meeting of December 2, 1926)

Delivering an address at the last meeting of the year is one of the pleasant and important duties required of its President by the Constitution of the Hawaiian Entomological Society. The meeting today represents the close of the twenty-second year of the existence of our society. In reviewing the addresses of the presidents during the past twenty-one years, I notice that all of them, excepting two, deal with strictly entomological subjects. It is important that a presidential address have a topic which will be of interest to the organization before which it is given. Past addresses have been of this nature, and, as a rule, have presented valuable and new observations in various branches of entomology. They have been given by men who were doing strictly entomological work, from which it was comparatively simple to select an appropriate subject. This address has been prepared by one who is able to devote only part of his time to such work, and consequently some difficulty was experienced in selecting a subject bearing on Hawaiian entomology, and which would be of interest to the Society. The following topic was finally chosen.

Some Observations in Hawaii on the Ecology of the Mediterranean Fruit Fly Ceratitis capitata Wiedemann and Its Parasites

The study of insect Ecology as a definite branch of entomology is comparatively new. Many ecological observations have been made in connection with entomological work since insects were first studied, but few of them have been published as such. Some investigators believe that study of environment is the most important phase of working out methods of control for injurious insects. One worker, Mr. Charles H. T. Town-

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send, after giving much study and thought to ecology and its relation to entomology, concludes that "Environment work will be the first and last steps in the insect control of the future." (Ecology, Vol. 5, 1924). While this conclusion may be somewhat too highly comprehensive, the analysis which led to it is logical and well worked out. It is difficult to express the results of study of insect environment, unless it is divided into more or less generally recognized divisions. Mr. Townsend, in the paper above referred to, has made such divisions in an admirable manner, and for the purpose of outlining the observations now being presented, I should like to follow as nearly as possible his divisions.

He divides insect environment into three classes of elements, i. e. media, factors, and controls. Media include air, water, soil, and certain secondary and tertiary media. Factors are heat, sunlight, rainfall, atmospheric humidity, atmospheric pressure, wind, soil texture, soil moisture, vegetation, food supply, predators, and various parasites and diseases. Controls consist of topographic features of the locality, and climatic conditions such as day, night, seasons, and seasonal fluctuation. A mere glance at the large number of divisions in the study of insect environment as they have just been listed, is indicative of the enormous field to be covered in working out the ecological data of even one insect.

In presenting these observations on the fruit fly and its parasites in Hawaii, no attempt is made to give complete information on the effect of environment on these insects; but to bring before you various environmental effects which have been observed since they became established in Hawaii. Some of the observations were made by Dr. E. A. Back and Mr. C. E. Pemberton. A number have already been published in papers covering other subjects, and could be easily overlooked by the student of ecology. Consequently, I have endeavored to bring together the majority of these observations, both published and unpublished, for your consideration.

The history of the successful introduction and establishment of beneficial insects in Hawaii, as well as the rapid multiplication and spread of injurious insects here, is well known. Much of our success with beneficial insects has been due to the careful selection of the insects to be introduced, but much credit must be given to favorable environmental conditions. Our Hawaiian environment is so favorable to the propagation of insects that many have come to believe that it is only necessary for an insect to arrive here alive and its establishment is assured. As a matter of fact, many introduced insects do not become established. In "The Hawaiian Planters' Record" for October, 1925, Swezey lists 247 species of beneficial insects which have been introduced into Hawaii since 1890. Of this number 153, or over 61 per cent of the total species introduced, are listed by him as failing to become established. This would indicate that the supposedly very favorable factors of Hawaiian environment are not conducive to the propagation of many insects.

The Mediterranean fruit fly *Ceratitis capitata,* which gained entry into Hawaii about 1910, found itself in an almost perfect environment, and it multiplied and spread rapidly. The effect of some of the individual factors of environment have been noted. The factor of heat is very favorable to its reproduction in littoral Hawaii. Here the temperature ranges from 56° to 85° F. and the fruit fly is able to produce 15 to 16 generations a year. In the higher elevations the temperature decreases and the period of development increases accordingly until, at an elevation of 4,500 feet, there appears to be only one generation a year. The fly has been found, however, in fruits in practically every locality where fruits are grown in Hawaii, indicating an adequate amount of heat for its development wherever the temperature is high enough to grow fruits suitable for Hawaiian conditions.

Reduction in the amount of heat through the application of cold storage has been extensively advocated as a method of killing maggots which may be within infested fruits that are intended for shipment to countries where this pest does not exist. A great number of experiments which have been made in Hawaii and elsewhere, show that the immature stages of the fruit fly have considerable resistance to low temperatures, and that this resistance may be affected by the temperatures in its natural environment. In Hawaii, it was found that a mature larva was able to survive for 45 days in cold storage where the temperature range was from 40° to 45° F. At a temperature range of 32° to 33° F. one mature larva survived 18 days refrigeration in fruits wrapped in paper and packed in excelsior, but none were found to survive longer. In South Africa 33 out of 49 *C. capitata* larvae were found alive in peaches which had been held in cold storage for six weeks at a mean temperature of 33.972° F. These fruits were likewise wrapped in paper and packed in excelsior. The difference in resistance of the larvae to lack of heat in the two experiments, is probably due to the environment in the two countries where they and their ancestors had been living. In South Africa, where the infested fruits were collected for the experiment, the flies have been subject to both colder and warmer temperatures than those existing in Hawaii. It seems reasonable to conclude that the more changeable temperatures of South Africa have produced a race of flies which are more resistant to temperature changes than those in the coastal regions of Hawaii where very little variation in temperature occurs during the whole year. Excessive heat as well as deficient heat, proves fatal to immature stages of the fruit fly. Observations have shown that a large proportion of the larvae in fruits which are exposed to the direct rays of the sun are killed by the excessive heat.

The factors, sunlight, rainfall, atmospheric humidity, and atmospheric pressure, all probably have some effect on the development of *C. capitata*. No outstanding features have been noted, although it is evident they exert no great check on its development in Hawaii.

The factor of food was doubtless the greatest cause of the rapid increase in abundance and early spread of this pest after it reached the shores of Hawaii. The first measure of control tried after its arrival, was to decrease its food supply by attempting to destroy all host fruits as soon as they developed. It was soon discovered, however, that there were between 70 and 75 species of host fruits in Hawaii, in which the larvae of the fruit fly could develop. Some of these fruits, notably the guava, were widely distributed in locations inaccessible to man, and the attempt to modify this particular factor of its environment was abandoned. The abundance of host fruits in Hawaii throughout the year provides the fruit fly with a constant supply of food, and results in an abundance of flies at all times.

In the long list of host fruits may be found certain ones that are detrimental to the development of the fly and which help in a small way to reduce its numbers. The most important of these are certain citrus fruits which have a high resistance to infestation by the fruit fly. It has been shown by Back and Pemberton (Jour. of Agri. Research, 1914-15) that the mortality of eggs and larvae of the fruit fly in the skin and rag of most citrus fruits ranges from 89 to 99.8 per cent, when the eggs are deposited in a fresh puncture. While making the puncture, the female fly ruptures some of the oil cells in the skin of the fruit, releasing the oil which flows into the puncture and forms a medium which is fatal to a large number of the freshly deposited eggs. Most of the few larvae which do succeed in hatching find the rag so impervious that only occasionally are they able to reach the pulp and damage the fruit. Certain varieties of avocado (*Persea gratissima*) furnish a medium detrimental to eggs of the fruit fly. Of 1,291 eggs deposited in avocados, 54 per cent failed to hatch. This was probably due to the extra oily nature of the pulp in the fruits under observation. The green banana (*Musa* sp.) with an abundance of tannin laden juice in its skin is nearly always fatal to the eggs and young larvae of the fruit fly. The fruits of the satin-leaf (*Chrysophyllum oliviformae*) and the star apple (*C. cainito*) exude a milk-like viscid juice when punctured by the female fly. Before her eggs are deposited this juice often congeals and attaches the fly to the fruit where she eventually dies. It is not uncommon to see 12 to 15 dead flies securely glued to the surface of a star apple. Grapes (*Vitis* sp.) grown in Hawaii are very seldom infested. A recent examination of Emporer grapes, which were imported from California and subjected to attack by *C. capitata* in the laboratory at Honolulu, showed a very high mortality among the eggs. Observations of 2,251 eggs showed that 86 per cent failed to hatch, due doubtless to a lack of oxygen in an unfavorable medium. While the species of host fruits of the fruit fly are numerous in Hawaii. and provide an abundant food supply for its immature stages, a number provide very unfavorable media for its development, and act in a small way to decrease its numbers.

The number of predators present in Hawaii when *C. capitata* first arrived was not a sufficient or important enough factor in its environment to noticeably check its spread or control it in any one locality. Certain wasps of the genus *Crabro* store the adult flies in their nests as food for their young. A nest of *Crabro tumidoventris* containing a number of adults has been reported; and a nest of *C. unicolor,* in which the food supply was almost exclusively *C. capitata,* has been observed. The small brown carnivorous ant *Pheidole megacephala* (Fabricius) preys upon the larvae in fallen fruits and when they leave the fruits to pupate. Experiments have shown that the number destroyed by this ant is important in reducing the abundance of the fruit fly about Honolulu. In some species of fruits they have been observed to destroy five-sixths of all the larvae developing. While the destruction in some other species of fruits where the larvae are less accessible would be less, the check by this ant on the development of the fly is important.

The factor of parasites, which was introduced into the Hawaiian environment of the fruit fly by man, has been of the most economic value; and illustrates one method of combating an insect by producing an unfavorable environment by the introduction of a factor from abroad which is detrimental to its development. Four species of parasites, *Opius humilis* Silvestri, *Diachasma tryoni* Cameron, *D. fullawayi* Silvestri, and *Tetrastichus giffardianus* Silvestri, were brought to Hawaii by the Territorial Government in 1913 and 1914, and have been of much value in checking the ravages of this pest. During the past eleven years they have destroyed each year from 33.2 to 56.4 per cent of all of the larvae developing in fruits about Honolulu. While this amount of parasitism has not reduced the fly sufficiently to eliminate infested fruits, most fruits of commercial importance can be harvested without infestation provided they are removed from the trees as soon as they have reached a sufficient stage of ripeness.

Some observations have been made on the effect of various phases of environment on the development of the four species of parasites already mentioned. Here we have an example of insects which pass part of their lives in three classes of media. The egg and part of the larva stage is passed in a tertiary medium, composed of the fruit fly larva which is within the host fruit, a secondary medium. When the host maggot leaves the host fruit to pupate it often becomes a secondary medium within which the parasite passes the remainder of its larva and all of its pupa stage. The adult stage is passed within the air, a primary medium. The effect of these media upon the development of these parasites will be discussed later.

The medium within which the host maggot lives has an important effect upon the ability of parasites to attack it, and exerts a great influence upon the amount of control accomplished by them. The Opiine parasites, *O. humilis, D. tryoni* and *D. fullawayi* deposit their eggs within the host maggots by inserting their ovipositors through the skin of the fruit and into any host larvae within reach. It can easily be seen that fruits with thick pulp offer an opportunity for the host maggots to tunnel so far from the surface that a large percentage of them cannot be reached by the parasite's ovipositor, resulting in a low amount of parasitism. Larvae in fruits such as coffee cherries, which have very thin pulp and large seeds, are subject to parasitism readily and the percentage killed is large. For example, the parasitism by these three parasites over a period of one year of maggots in orange, *Citrus aurantium,* was 6.5 per cent; guava, *Psidium guajava,* 15.1 per cent; and mango, *Mangifera indica,* 22.9 per cent, all of which are fleshy fruits with deep pulp. Parasitism of maggots over a similar period in Indian almond *Terminalia catappa,* a fruit with a large seed and fairly thin pulp, was 49.1 per cent. The parasitism in coffee cherries has always been well over 90 per cent, and has nearly eliminated maggots in coffee cherries in the Kona coffee fields.

Records of the average number of larvae per thousand cherries from these fields have been secured for purposes of comparison, by holding the cherries over sand and recording the larvae emerging. This method of handling causes early fermentation of the coffee cherries which results in the death of some larvae before they emerge, and a record of the total number of larvae is not secured. However, the comparison of records over a series of years from collections of fruit all handled alike, gives a good indication of an increase or decrease in infestation. The number of maggots secured in this manner was 765 per thousand cherries in 1917, 42 per thousand in 1923, 33 per thousand in 1924, and 19 per thousand in 1926. A comparison of these figures shows a decrease of over 97 per cent in infestation of coffee by *C. capitata* in the Kona coffee fields; and gives an idea of the ability of the three parasites under consideration to destroy larvae of the fruit fly which are developing in a medium where they are highly subject to parasitism.

The medium in which the parasite larva lives has a great influence on its form and rate of development. In the case of the three opiine parasites already mentioned, the newly hatched larva finds itself in the medium of the host larva. It is equipped with a heavily chitinized head bearing a pair of strong and sharp sickle-like mandibles. This highly organized head structure is evidently provided for the purpose of enabling the parasite to separate its food, which consists solely of fatty tissue, from the internal structures of its host; and to protect itself from other parasite larvae within the same host maggot. As long as the host is in the larva stage it is subject to parasitism by any one of the opiine parasites, and superparasitism has often been noted. The food supply in one host larva is sufficient for the development of only one parasite, and in the case of superparasitism a battle is waged until only one living parasite is left. A number of fruit fly larvae have been dissected, each of which revealed one living parasite larva as the sole survivor of 8 to 10.

When the host larva leaves the fruit and forms the puparium, the medium surrounding the parasite has changed greatly and has an almost immediate influence upon it. The danger of superparasitism is past, histolysis occurs changing the food supply from a semi-solid to a liquid. The parasite no longer needs a strong head structure and sharp mandibles for fighting and laceration of food and casts them off with the first molt. The resulting second instar larva has a soft and inconspicuous head and mandibles, a sluggish body, and is well equipped for life in its new medium. In this connection it is of interest to note that the first stage parasite larva never molts until the host attempts to pupate. This has resulted in wide variations in the length of the first instar. When eggs were deposited in host larvae about to pupate, the shortest duration of the first instar was 1½ days; but when eggs were deposited in young larvae, several instances were observed where the first instar covered a period of 8 days.

The effects of the host media upon the development of the tracheal system of the opiine parasites are of interest. The first instar, living in the semi-solid medium of the host larva, has a well defined but simple treacheal system. Although no spiracles are present, the tracheae soon fill with air, probably by osmosis from the surrounding media. The second and third instars are passed in the liquid medium within the puparium of the host. Tracheae are evidently useless in a liquid medium containing little or no air, and no tracheal system can be found in either of these instars. When the larva molts into the fourth instar, or the mature stage, very little of the liquid medium of the host remains, and it finds itself with an air space surrounding it. To adapt itself to this new medium, a well defined tracheal system is present which connects with nine large, open stigmata on each side of the body. The development of the tracheal system in the various stages of the parasitic larva is directly related to the amount of air in the media surrounding them.

The question is often asked as to what the fruit fly parasites will attack should they kill all the fruit flies. Entomologists know that parasites have their natural hosts to which they are usually confined. Comparatively little is known, however, about the cause for the inability of a parasite of a particular insect to reproduce itself in all insects which belong to the same group as the host. This is probably almost entirely due to environmental conditions. It has been found that the opiine parasites of *C. capitata* in Hawaii cannot develop in the melon fly *Bactrocera cucurbitae,* a species with closely related habits. Oviposition in melon fly larvae was readily secured in the laboratory, but no parasites developed. Dissection of the parasitized larvae showed that the body fluid was an unfavorable medium for the eggs, and that they became encysted in a mass of transparent cellular material and killed. It was found also that the eggs of *Tetrastichus giffardianus* were encysted in a similar manner, and it was thought that this chalcid could not develop in *B. cucurbitae.* It was discovered later, however, that when the melon fly larvae had been attacked by the melon fly parasite *Opius fletcheri* Silvestri and subsequently parasitized by *T. giffardianus,* some of the latter always developed. Parasitization by *O. fletcheri* seemed to eliminate the ability of the melon fly to encyst the eggs of *T. giffardianus.* Since *T. giffardianus* deposits from 8 to 30 or 40 eggs in a single host larva, which hatch into larvae that develop rapidly, the larva of *O. fletcheri* was killed, probably by starvation, in every instance but one. No instance was observed where one of the opiine fruit fly parasites was able to develop in the melon fly even though the host had been previously parasitized by *O. fletcheri.*

On the other hand, *O. fletcheri* can be readily reared from *C. capitata* in the laboratory, with no apparent detrimental effects on its development. In the field, *O. fletcheri* very seldom parasitizes larvae of the fruit fly. Records of fruit fly parasitism over a period of over 10 years, during which time hundreds of thousands of parasites have been reared from larvae parasitized in the field, less than 50 *O. fletcheri* have been secured. Although *O. fletcheri* can be easily induced to attack the fruit fly in the confinement of the laboratory, the fact that it seldom breeds in *C. capitata* under natural conditions, strongly indicates that some factor of the environment of the fruit fly is not attractive, and possibly repulsive to it.

Since there are no secondary parasites affecting the development of the parasites under consideration, the factor of parasitism is not important as a phase of their environment. *Diachasma tryoni* and *D. fullawayi* are not parasitic on each other or on *Opius humilis,* but are very detrimental to the development of *O. humilis.* As previously referred to when super-parasitism by the parasites just mentioned occurs, all but one parasite within each host larva are killed. When *O. humilis* occurs within the same larva with either of the two species of *Diachasma,* it is invariably killed. The presence of these two parasites creates an unfavorable factor in the environment of *O. humilis* and decreases its efficiency enormously. In 1915 it parasitized 31.5 per cent of all the larvae developing in fruits about Honolulu; but the influence of *D. tryoni* and *D. fullawayi* upon it, gradually decreased its effectiveness until in 1923 it parasitized only 4.1 per cent. It increased in effectiveness in 1924 and 1925, when it parasitized 14.5 per cent each year.

In coffee cherries in Kona, this influence has been even more marked. In this fruit the total parasitism has always been high and superparasitism must have been correspondingly high. The first records of parasitism of *C. capitata* in Kona coffee, secured in the early part of 1915, show that *O. humilis* parasitized from 59 to 97 per cent of all the larvae developing. The two species of *Diachasma* became abundant soon after, and the effectiveness of *O. humilis* rapidly diminished. The fruit fly larvae from 18,955 coffee cherries collected in Kona in 1926 did not produce a single *O. humilis*. In this instance by introducing parasites as a factor to create an unfavorable environment for the development of the Mediterranean fruit fly, a factor so unfavorable to the development of one of the most valuable parasites was introduced so that the effectiveness of that parasite is very small.

Insect ecology is rapidly approaching a place of first importance in the work of the economic entomologist. With a knowledge of the ecological factors affecting the development of insects, he is often able to create an unfavorable environment to replace a favorable one in his fight against injurious insects, and in the case of beneficial insects, assist them by the introduction of favorable ecological factors. In presenting these observations on the ecology of *C. capitata* and its parasites in Hawaii, no attempt has been made to give complete ecological data. The more important effects of environment upon the development of these insects since their introduction into Hawaii have been brought together, however, and it is hoped they will add something to the importance of insect ecology in the work of the applied entomologist.