

## BIOCLIMATIC STUDIES OF THE MEXICAN FRUIT FLY

### **P. S. Messenger**

*Assistant Entomologist in Biological Control, University of California Agricultural Experiment Station. (Present address: P.O. Box 1033, Brownsville, Texas.)*

### **N. E. Flitters**

*Entomologist, Fruit Insects Section, Entomology Research Division, Agricultural Research Service, U.S. Department of Agriculture. (Present address: P.O. Box 1033, Brownsville, Texas.)*

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California fruit growers noted with interest and much concern the discovery early in 1954 of an adult Mexican fruit fly, **Anastrepha ludens** (Loew), in one of a series of insect survey traps just below the international border in northwestern Mexico. The potential consequences of this occurrence of an insect pest hitherto known only from eastern and southern Mexico, Central America, and south Texas were serious. Quarantines and restrictions in commodity movement, eradication operations, destruction of all fallen, prematurely colored, or ripe host fruits, and, should infestations become well established and widespread, costly control procedures were factors confronting these growers.

The subsequent finding of additional individuals of this species in northern Baja California, at Tia Juana and at Mexicali, and finally the taking of an adult female fruit fly at San Ysidro in San Diego County resulted in the establishment of a state Interior Quarantine (Messenger 1954) directed at the movement from the vicinity of San Ysidro of citrus fruits, various deciduous fruits, and many tropical and subtropical fruits grown in Mexico and California.

This new insect problem in California has already been brought to the attention of avocado growers (Steinweden 1955). Up to 1954 avocados were not included in the list of host fruits infested by the Mexican fruit fly, and the Interior Quarantine mentioned above did not refer to this commodity by name, although it did provide for the inclusion of any fruits subsequently determined to be susceptible to infestation by this insect pest. During 1954, however, several varieties of avocados grown in southern California were tested in the laboratory for susceptibility to infestation by adult Mexican fruit flies, and positive results were obtained with the widely grown varieties Nabal, Ryan, Fuerte, Zutano, Puebla, and several others unnamed (Harper 1955). Varieties Anaheim and Hass gave negative results. Further, during the past several years research workers of the Mexican Fruit Fly Laboratory, U. S. Department of Agriculture, Mexico City, have been finding light infestations of the Mexican fruit fly in avocados grown in various localities in Mexico (Bush 1957). Infested avocados have also been intercepted at the

Texas border by Federal Plant Quarantine authorities (Stone 1942). Hence avocados ought now to be included in the host list of this species and to be considered in regard to the Mexican Fruit Fly Interior Quarantine.

Subsequent to the finding of the fruit fly at San Ysidro, the program of research on this pest at Mexico City by the U. S. Department of Agriculture was enlarged and accelerated. Various agencies of the State of California, including the University of California Agricultural Experiment Station, entered into cooperative research programs with the Federal agencies in efforts to obtain additional information concerning the fruit fly's biology, including a study of the effect of climatic factors on the ability of the pest to establish itself in various areas of the United States.

In connection with this latter study, the California Agricultural Experiment Station, in cooperation with the Fruit Insects Section of the Entomology Research Division, U. S. Department of Agriculture, is conducting research in Brownsville, Texas, on the bioclimatic characteristics of the Mexican fruit fly. The aim of the project is to determine the extent to which the northward spread of this species into such states as California may be expected to be limited because of climatic factors. The studies, which include the evaluation of several California climates, are based primarily upon the simulation of certain climatic factors in large air-conditioned cabinets termed bioclimatic chambers.

## **BIOLOGY OF ANASTREPHA LUDENS**

Before describing the techniques and results of the bioclimatic studies, certain basic aspects of the general biology of the Mexican fruit fly should be mentioned. This insect pest, a member of the fruit fly family Tephritidae, is indigenous to northeastern Mexico and is now distributed more or less generally throughout tropical and subtropical Mexico and Central America (Fig. 1) (Stone 1942, Baker et al. 1944). The species has also been reported occurring in Yucatan (Mexico) and as far south as Panama and northern South America (Crawford 1927 Hoidale 1952), although these findings have not been verified in recent surveys for the pest. As California citrus growers well know, the pest extends its normal range periodically from northeast Mexico into the lower Rio Grande Valley of Texas, being first reported from this latter area as early as 1903 (Sanderson 1908, Smith **et al.** 1933). On the west coast of Mexico, the fruit fly has gradually extended its way northward, reaching Culiacan (Sinaloa) by 1933 (Baker **et al.** 1944), and Hermosillo (Sonora) in 1953 (Harper 1955). North of Hermosillo there seems to be nothing in the way of potential host material or satisfactory environment for the fruit fly, this region being largely an arid desert. Periodic extension of its range from Hermosillo northward, in the same sense as occurs in southern Texas, does not appear probable.

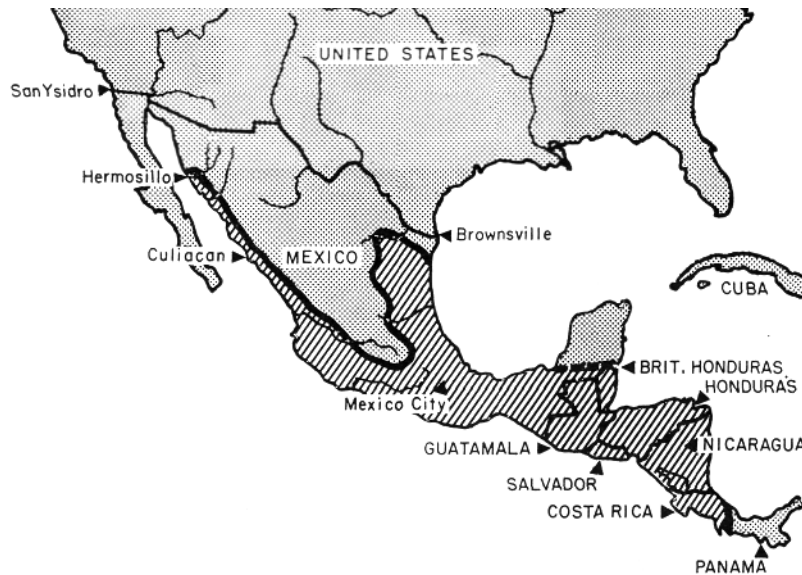


Fig. 1. Presently known distribution of the Mexican fruit fly, *Anastrepha ludens* (Loew), in Mexico and Central America. In northeastern Mexico the range of the species extends northward periodically into the southern tip of Texas, but infestations in this area have not been permanent.

The Mexican fruit fly is subtropical in nature, having several generations a year but no overwintering stage that undergoes diapause or hibernation. The eggs are laid in fruits and hatch into larvae that feed within until fully developed. The larvae then emerge from the fruits and enter the soil to pupate. Adults emerge from the puparia and work their way out to the open air. In the insectary at Brownsville, maintained at 75-80° F. with optimum prepared food materials available, the egg stage lasts from 3.5 to 4.5 days, the larval stage from 10 to 12 days, the pupal period from 16 to 19 days, the adult preoviposition period from 12 to 16 days, and the average adult longevity from 45 to 60 days. In Mexico, in most host fruits the developmental periods are somewhat longer than those found in the insectary. Under various conditions both in the field and in the laboratory, the egg stage has been prolonged to as much as 12 days, the larval period to 35 days, the pupal period to over 100 days, the preoviposition period of adults to 34 days, and the maximum longevity of females, 11 months, and males, 16 months (McPhail and Bliss 1933, Darby and Kapp 1934, Baker **et al.** 1944).

The host range of the Mexican fruit fly is given in detail in the article by Baker **et al.** (1944). Included are most citrus fruits but lemon and sour lime, many deciduous fruits, such as peach, pear, apple, plum, apricot, many tropical fruits, such as mango, guava, pomegranate, white sapote, and the wild fruit known as yellow chapote. As indicated above, to this list should now be added certain varieties of avocado.

## MATERIALS AND METHODS

The basic design of the nine bioclimatic chambers now being used at Brownsville has been described in detail (Flitters, Messenger, and Husman 1956). For purposes of the present discussion, these chambers may be described briefly as follows. Each chamber

is similar to a walk-in refrigerator, being fitted with two doors separated by a 4-foot vestibule, and having an inner work space providing floor area 6 feet by 6 feet for conducting experiments. Attached to the chamber are various air-conditioning controls and devices that permit the air circulating within the chamber to be heated, humidified, cooled, or dried, as desired. A major feature of these chambers lies in their capability of controlling temperatures and humidities in smoothly varying patterns such as occur naturally. Temperatures may be controlled to within plus or minus one degree Fahrenheit over the range from  $-5^{\circ}$  to  $+125^{\circ}$ . Humidities, within this same temperature range, may be controlled to within plus or minus 3% relative humidity over the range 20% to 98%. At temperatures above freezing, humidities may be controlled to as low as 10%. Lights within the chambers are automatically turned off and on by means of time clocks, and the settings of these clocks are periodically varied in order to duplicate the variations in photoperiod as these occur naturally.

Since it is desired to estimate the potential limits of the Mexican fruit fly spread into the United States as influenced by climate, the different climatic conditions studied thus far have been primarily those of the southernmost states, from California on the west, through Texas to the Gulf Coast, and to Florida and South Carolina in the east. In California, emphasis has been given to climatic conditions occurring in the south, including those of Chula Vista, El Centro, Riverside, and Compton. Two northern California sites are being studied, San Jose (Santa Clara County) and Sebastopol (Sonoma County). Sites of importance in other states are: Tempe, Arizona; Weslaco and Brownsville, Texas; Houma, Louisiana; Greenwood, Mississippi; Maiden, Missouri; Orlando and Monticello, Florida; Fort Valley, Georgia; and Charleston, South Carolina.

Temperatures and relative humidities over an entire year are simulated in a given study. Initially, cages containing mature adult fruit flies and small samples of each of the individual stages of the fruit fly are introduced into the chamber. Weekly, the adult flies are fed and watered, and any loss in numbers due to mortality is replaced.

Three times each week, throughout the study, these mature adult flies are allowed to oviposit for a day or so in mature grapefruits; the fruits are then held in the chamber until any consequent infestation develops to maturity and yields progeny. The individual samples of the different stages are observed daily until they transform to the next subsequent stage, after which the samples are discarded. Progeny flies from the mature parents are segregated and maintained within the chamber in additional cages until they mature and reproduce, or until they die out. Daily observations are made of adult activity, including such events as normal movements, feeding, mating, and oviposition.

## **RESULTS**

The results of the biological observations were summarized and correlated with the climatic conditions that were being simulated within the chamber during the time concerned. Changes in the speed of development, in the number of progeny produced, in the rapidity of development of the individual stages, and in the activity of the adult fruit flies as influenced by the climatic factors being simulated were determined. Threshold values, optimal conditions, and inhibitory levels of temperature and humidity were calculated after the data were summarized, and estimates were finally made of the

suitability of the climate under investigation for supporting infestations of the insect.

Figure 2 illustrates the general climatic conditions simulated, and summarizes some of the results obtained, for Chula Vista, California. The climatic records for this site were collected in the field during the period March 1953 to February 1954.

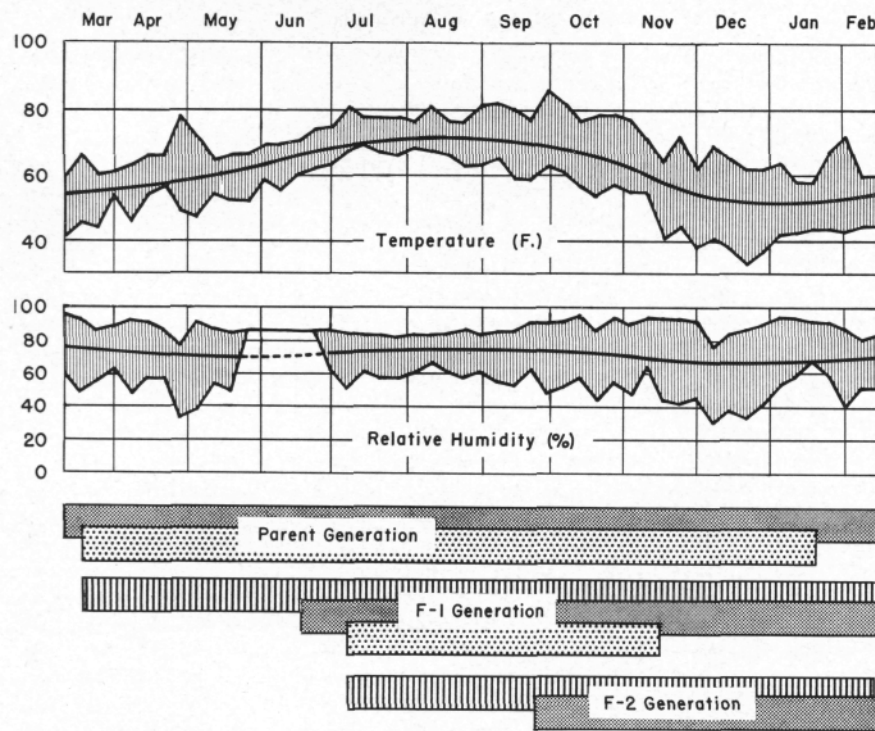


Fig. 2. Temperatures and relative humidities (weekly mean maximums and minimums, and monthly means) simulated for Chula Vista, California. Horizontal bars represent the periods during the study in which immature forms (heavy vertical lines) and adults (fine stipple) were present, and adult breeding (coarse stipple) occurred for the different generations produced.

The Chula Vista annual temperature pattern was quite mild. Rarely did weekly average temperatures drop below 60° F. or rise much above 80° F. The proximity of this site to the ocean resulted in narrow diurnal fluctuations in temperature throughout the year. Relative humidities were quite constant and comparatively high, with average humidities usually between 60 and 80%.

Mexican fruit fly reproduction and development was comparatively heavy and continuous throughout the spring, summer, and fall months. In the winter period reproduction fell off, but development of immature stages of the insect was uninterrupted, although developmental periods were extended. A second (F-1) generation of fruit flies was produced by early summer, and this new generation began reproducing shortly thereafter, remaining active throughout the summer and fall. By early fall a third (F-2) generation of fruit flies began emerging and continued to emerge intermittently throughout the winter.

In summary, it can be stated that in such a climate as this, the Mexican fruit fly can breed almost continuously throughout the spring, summer, and fall, and that development of immature stages proceeds throughout the year. Three generations of fruit flies can be produced.

Table 1 gives certain climatological data pertaining to the localities studied. Certain of these data have been selected because of their bearing on the responses of the Mexican fruit fly. Mean and mean maximum temperatures are provided because they indicate the general level and the amount of fluctuation, respectively, of this factor at each site investigated. Mean maximum temperatures during the winter period show whether adult oviposition could occur. This adult activity has only been observed when day temperatures were 55° F. or above. Nights with temperatures below 32° F. reduce the longevity of adults excessively. Days with temperatures above 95° F. interfere with adult reproduction, and also reduce longevity excessively.

Table 2 summarizes the reactions of the fruit fly to the two important seasons of the year at each site and also gives the breeding season and the number of generations produced. In this table a normal response is one in which adult feeding, mating, and oviposition occur more or less regularly, although cooler conditions may tend to reduce the degree of each activity somewhat. Inactive responses are those in which the adults are not able to mate or infest grapefruits, although feeding may continue and longevity may be extended. Short-lived responses are those in which the adults are able to reproduce, but high temperatures cause increased mortality. Lethal responses are those in which the temperatures cause excessive mortality and completely interfere with other activities. For the young or immature stages, normal responses are those in which the developmental periods are optimal. Slow growth indicates extended developmental periods due to low temperatures.

The lowest daytime temperature at which fruit flies infested grapefruits was 55° F. during the month of February in the Fort Valley study. Several infestations originated during days with temperatures of from 56° to 58° F. in the Riverside (January-February), Greenwood (March), and Maiden (November) studies.

In certain studies, the immature forms were observed to overwinter; i.e., eggs laid in the fall led to adult emergence the following spring. The low temperatures encountered caused a considerable extension of the developmental periods in such cases. The lowest average temperature allowing such overwintering was 53.4° F. during the period November to April in the Riverside study. Total duration of development lasted 163 days, which was also the longest developmental period found in the investigation. Other overwintering infestations were observed in the Chula Vista study (55.5° F. over 122 days), the Compton study (60.2° F. over 100 days), and the Orlando study (60° F. over 112 days).

Table 1. Climatological data for the sites studied to date.

Site	Winter (December-February)			Summer (June-August)		
	Temperature, °F.		No. of Nights below 32° F.	Temperature, °F.		No. of Days above 95° F.
	Mean	Mean Maximum		Mean	Mean Maximum	
Chula Vista, Calif.	51.9	63.4	3	69.2	74.9	0
Riverside, Calif.	50.0	64.8	17	73.3	92.5	37
El Centro, Calif.*	57.0	69.7	1	88.7	103.0	55
Compton, Calif.	54.0	67.4	0	68.4	78.7	1
Brownsville, Texas	65.1	73.8	0	83.0	90.1	0
Greenwood, Miss.	48.7	56.9	13	79.4	89.7	9
Greenwood, Miss.†	45.9	54.0	26	82.2	90.3	7
Malden, Mo.	37.9	46.4	51	78.2	87.8	2
Orlando, Fla.	60.4	70.6	3	79.4	88.7	3
Fort Valley, Ga.	48.1	56.3	16	79.2	89.6	12

\*The summer at El Centro includes only the months of June and July.

†Greenwood was studied for two successive years. The summer of the second year includes only the months of June and July.

Table 2. Seasonal response, reproductive period, and number of generations produced by the Mexican fruit fly, ANASTREPHA LUDENS (Loew), in the climates studied to date.

Site	Summer Response		Winter Response		Reproductive Period	No. of Generations
	Adults	Young	Adults	Young		
Chula Vista, Calif.	Normal	Normal	Inactive	Slow growth	Mar.-Nov.	3
Riverside, Calif.	Short life	Normal	Inactive	Slow growth	Apr.-Dec.	2
El Centro, Calif.	Lethal	Lethal	Normal	Slow growth	Nov.-May	2
Compton, Calif.	Normal	Normal	Inactive	Normal	May-Dec.	3
Brownsville, Texas	Short life	Lethal	Normal	Normal	All year	2
Greenwood, Miss.	Normal	Normal	Lethal	No growth	Mar.-Oct.	2
Malden, Mo.	Normal	Normal	Lethal	No growth	Apr.-Oct.	2
Orlando, Fla.	Short life	Normal	Normal	Normal	All year	3
Fort Valley, Ga.	Normal	Normal	Lethal	No growth	Feb.-Oct.	2

## CONCLUSIONS

From the information gathered to date it appears that the Mexican fruit fly would be able to breed throughout the year in climates like those of Brownsville, Texas, and Orlando, Florida. Although breeding may be interrupted in the winters, overwintering of immature forms could occur in climates such as Chula Vista, Riverside, and Compton, California.

The various summer conditions studied showed that summer heat in climates like those of Brownsville, El Centre, and possibly Riverside, caused adults to die soon. Under such conditions newly emerged adults were unable to mature sexually before dying. On the other hand, summer temperatures in the coastal areas of southern California should permit normal adult development and activity. Hence, since the Mexican fruit fly can breed continuously during the spring, summer, and fall, and the immature forms can overwinter, it appears that continuous populations could be maintained in these coastal areas.

With a continuous source of fruit flies in the coastal areas of southern California, it seems probable that, by analogy to the situation in south Texas, the Mexican fruit fly might annually extend its range from these areas into the interior valleys each fall, though probably the following summer temperatures in these interior regions would

either kill the infestations off or drive the adults back to the coast or into foothill regions.

In a similar sense, continuous populations of the fruit fly would probably become permanent along the Gulf Coast and in Florida. Dispersal from these centers could then be expected in the spring and summer months up into the Mississippi River Valley and northward from Florida along the southeastern seaboard. In these cases cold winter temperatures would drive the populations southward each year.

## **SUMMARY**

For the purpose of estimating the potential distribution of the Mexican fruit fly, **Anastrepha ludens** (Loew), in the United States, as governed by climatic factors, natural temperature and humidity patterns representative of various agriculturally important localities in the southern states have been simulated in bioclimatic chambers, and the effects of such conditions on the Mexican fruit fly have been observed.

The Mexican fruit fly was found able to breed throughout the year under the climatic conditions of Brownsville, Texas, and Orlando, Florida. Immature forms were seen to overwinter in conditions representing Chula Vista, Riverside and Compton, California. Summer heat caused excessive mortality of adult flies at Brownsville and at El Centro, California, and to a lesser extent at Riverside. Three generations of fruit flies per year developed in the Chula Vista, Compton, and Orlando studies; in all other studies only two generations developed. The longest developmental period of the immature forms lasted over five months and occurred at an average temperature of 53.4° F.

It is concluded that permanent populations of the fruit fly could develop in the coastal areas of southern California and of the Gulf of Mexico, and throughout most of Florida. Dispersion from these centers of permanent infestation might then occur each fall and winter into the interior valleys of southern California, and each spring and summer northward into the lower Mississippi River Valley and along the southeastern seaboard.

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