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A Calendrical Method for Predicting Generation Cycles of the Mexican Fruit Fly, *Anastrepha ludens* (Diptera:Tephritidae), Triggering Citrus Quarantines in South Texas.

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ABSTRACT

The Mexican fruit fly is an invasive pest of citrus and other commercial fruits that triggers quarantine restrictions when it is detected in the United States. The citrus crop in south Texas is especially vulnerable to infestations because of its proximity to the border areas of Mexico where the pest is endemic. Under existing protocols an infested grove is placed under quarantine for a time equivalent to three life-cycles estimated by a degree-day model to be (754x3 =) 2262°D. Depending on the time of year when a grove becomes infested, the quarantine may last from 4-7 months. Under quarantine restrictions fruit cannot be shipped without fumigation. In practice the accumulation of degree-days is tracked from local US Weather Service data. Herein a calendar is provided that projects the expected duration of a quarantine for a fly detection for any week of the year based on historical weather records. Producers, packers and program managers can use the projection to plan treatment options.

Additional Index Words: Mexfly, degree-days, quarantine, citrus protocol.

The Mexican fruit fly, *Anastrepha ludens* (Loew) (Diptera: Tephritidae) is a major pest of commercial fruit, especially citrus, in Mexico. It is an invasive pest species that triggers quarantine restrictions when it is detected in the United States (Mangan et al. 1997). In order to protect the citrus crop grown in the Lower Rio Grande Valley of Texas, the U.S. Department of Agriculture operates a Sterile Insect Technique program that mass releases 100 million sterile Mexican fruit flies per week (Thomas et al. 1999).

The flies are mass reared at a facility near Edinburg TX, radio-sterilized, and then released by aircraft over 30,000 acres of citrus and the surrounding suburban areas on both sides of the Rio Grande (there are no commercial groves on the Mexican side of the valley). A trap grid of 2000 fruit fly traps, half in groves and half in dooryards, is in constant operation on the Texas side to maintain surveillance for incursions of this pest. Detection of an infestation places any grove within 500 m under quarantine. The fruit in an impacted grove cannot be moved out of the quarantine zone without a disinfesting fumigation treatment until the quarantine is lifted. Extra delimiting traps are deployed in the impacted grove, in addition to those already in place, and a fruit cutting regimen is initiated. Under the present protocols the quarantine is not lifted until three life cycles have passed without a further detection of the pest insect.

The life cycle generation time is determined by a degree-day model with input from official U.S. Weather Service data. Depending on the time of year when a detection occurs three life cycles could take as much as seven months causing a significant delay in harvesting operations. A quarantine triggered during the harvest season would last 4-5 months, or longer, which for practical purposes would extend past the harvest season. Once a grove is placed under quarantine a grower has the following options: 1) forego harvest, 2) harvest and sell locally, 3) harvest, fumigate and ship, or 4) delay harvest for 30 days during which time the grove is treated with a pesticide registered against fruit flies. For example, with three treatments of a ULV Malathion fruit fly bait formulation applied at ten day intervals, and assuming no further detections in the interim, the crop could be shipped from the impacted grove without fumigation, and/or, without the full three generation quarantine delay.

Such management decisions depend on prices, market contract obligations, condition of the fruit, and the proximity to the end of the harvest season. In order to assist grove owners, packers, and program managers considering these options a quarantine calender is herein provided that predicts the duration of a quarantine based on expected degree-day accumulations for the Lower Rio Grande Valley.

MATERIALS AND METHODS

The degree-day model used is the Standard Weather Bureau method, also known as the Means Method (Preuss 1983), which is,

$$[(\text{Max T} + \text{Min T}) / 2] - \text{base}.$$

The base for the Mexfly is 9.4°C with a level off in developmental rate at 31°C (Leyva-Vazquez 1988). In practice, the input for the degree-day model uses temperature data accumulated on a daily basis as reported by the National Weather Service for the station nearest the impacted grove. The National Weather Service operates 13 stations in the Lower Rio Grande Valley. For example, the historical average temperature in McAllen TX for the month of March is 23.1°C. Hence, for the typical March day the degree-day accumulation would be calculated thusly,

$$23.1 - 9.4 = 13.7 \text{ °D}$$

The total generation time for the Mexfly is estimated to be 766 °D (Thomas 1997). An adjusted value established by USDA-APHIS for quarantine purposes is 754 °D (see Borchert 2011). From the Weather Service data a running total of degree-days is kept until a number sufficient for three life-cycles (2262°D) has accumulated and the quarantine can be lifted. The US Weather Service reports historical averages in its monthly station summaries and these data are available from the National Climate Data Center web site: www.ncdc.noaa.gov/oa/ncdc.html.

Data from the monthly summaries were extracted from this source and provided here in Table 1 for three representative stations in the Lower Rio Grande Valley: Brownsville, Harlingen and McAllen. A mean temperature for the Valley as a whole was then calculated from these records. For example, for the month of January the historical averages for the three stations were: 16.8, 16.1 and 16.0°C, giving a mean of 16.3°C. Inserting this value into the model results in a calculated 6.9°D for a typical day in January. The predicted accumulation for the month is thus 31 x 6.9 = 214°D and this value is shown in the last column of Table 1 which also shows the calculated values for each month. The data in Table 1 can then be used to calculate generation time. For example, if a fly find was made on 15 January then over the rest of the month, 16 days, there would be a predicted accumulation of 16 x 6.9 = 110°D. For February and March the accumulation would be respectively 218°D and 425°D giving a total of 753°D, enough for one complete life cycle. In this manner the values were used for constructing the quarantine calendar which is based on a three life cycle quarantine duration.

RESULTS

By using the historical data in Table 1 a calendar was contructed that allows a direct reading of generation time for any detected infestation (Table 2). For example, for the purposes of the quarantine it is assumed that a fly trapped during Week 9 (early March), has oviposited the same week that it is captured,and thus its progeny would reach adulthood in a predicted 50 days, the time required to accumulate 754°D at that time of year. The next generation, beginning in Week 16 (mid-May), would be considerably shorter, around 41 days (6 weeks), because of warmer weather. Thus, the next generation would turn around at week 22 where 37 days is the predicted generation time. Hence, for three generations the quarantine duration would be a predicted (50+41+37 = 128 days) = 18 weeks. This number can be read off the third column of the quarantine calendar (Table 2). Thus for a detection in Week 9 the number in the corresponding column under Generation 3, in this example 18, predicts that the quarantine will end in (9+18) = Week 27. By using this calendar, program managers can predict the end of the quarantine for the date of any detection on a weekly basis and plan the implementation of restrictions accordingly.

DISCUSSION

It should be understood that the degree-day method is predicated on the concept that insect generation time is largely temperature driven. While this is generally true, temperature is not the only factor influencing Mexfly generation time. Actual emergence date for a generation of adults from the same oviposition can vary by a week or more from the expected mean generation time. This is because at the end of larval development additional environmental cues induce egression from the fruit to begin pupariation. Also, because traps are checked only once a week there is a built in imprecisión of up to 7 days. Thus, any precision obtained by using actual contemporary weather data instead of historical data would in most cases be inconsequential, a week or so at most. As an example of the application, on 15 April 2011 a wild Mexican fruit fly was captured at a trap in Bayview TX. According to the quarantine calendar (Table 2) a fly-find triggering a quarantine on that date, corresponding to Week 15, would remain under quarantine for a predicted 17 weeks, or, a total of 17x7 = 119 days. In tracking the actual weather data reported by the US Weather Service station in

Table 1. Degree days averaged by month for the LRGV during 2012 extrapolated from USWS Records[1].

Month	Mean Temperature (° C)			LRGV Mean		
	Brownsville	Harlingen	McAllen	T	DD	Monthly
January	16.8	16.0	16.1	16.3	6.9	214
February	17.1	16.6	17.9	17.2	7.8	218
March	22.8	22.3	24.1	23.1	13.7	425
April	26.9	26.5	28.0	27.1	17.7	531
May	28.1	28.1	28.7	28.3	18.9	586
June	29.6	29.8	30.3	29.9	20.5	615
July	29.3	29.7	30.5	29.8	20.4	632
August	30.7	31.5	32.3	31.5	21.6	670
September	29.0	29.4	30.9	29.8	20.4	612
October	24.4	24.8	25.8	25.0	15.6	484
November	21.3	21.4	22.2	21.6	12.2	366
December	17.1	17.0	16.6	16.9	7.5	233

[1] National Climate Data Center

Bayview beginning 15 April, the required accumulation of (754x3=) 2262°D was reached on 15 August 2011, in 121 days.

In reviewing the weather data for the Lower Rio Grande Valley over the last ten years, the greatest deviation from historical monthly means was 3°C. Because generation time for the Mexfly in south Texas is on the order of 1-3 months, for three life cycles 4-7 months, it would be exceptional to have a weather pattern that deviates from the long term average sufficient to cause a meaningful departure from the predicted. Moreover, because the duration of a quarantine triggered during the harvest season would in almost all cases extend beyond the end of the quarantine season, the week or so difference would be of no consequence.

On the other hand, a quarantine triggered during the growing season would inevitably delay harvest. If for example a detection were to be made in Week 25 (late June), a not unusual event, the quarantine would end in early October, which is the start of harvest season, and hence with little consequence. More seriously, a detection at the end of August would invoke a quarantine that would be in effect until early March, near the end of the harvest season. A week or so one way or the other in this case might cause a serious imposition. But inasmuch as no Mexican fruit flies have ever been detected in the month of August in the history of the Texas program, this scenario is unlikely. Hence, managers could simply impose the predicted quarantine duration and forego the exercise of tracking daily temperatures. A similar calendar could be generated for other fruit producing areas in other states that are vulnerable to Mexican fruit fly infestations, but it may not be appropriate to substitute the calendar method for the actual accumulation of degree-days because of differences in harvest seasons. Nonetheless, the calendar would be useful for projecting the duration of quarantines.

Table 2. Estimated quarantine duration for Mexican fruit fly infestations in the lower Rio Grande Valley based on degree-days. Projected life cycle in days for each calendar week of the year, followed by the duration of two generations in weeks and finally the full quarantine (3 generations). For example, a quarantine triggered by a fly find in calendar week 1 (Jan 01-07) would have a duration of 24 weeks. Therefore the quarantine would be lifted at week (24+1) = calendar week 25.

Calendar Week	Days	2 Gen	3 Gen	Calendar Week	Days	2 Gen	3 Gen
1 (Jan 01-07)	82	18	24	27 (Jul 02-08)	37	10	16
2 (Jan 08-14)	78	17	23	28 (Jul 09-15)	36	10	16
3 (Jan 15-21)	75	17	22	29 (Jul 16-22)	36	10	17
4 (Jan 22-28)	70	16	21	30 (Jul 23-29)	36	11	18
5 (Jan 29-F4)	66	15	20	31 (Jul 30-A5)	35	11	20
6 (Feb 05-11)	62	15	20	32 (Aug 06-12)	36	11	22
7 (Feb 12-18)	58	14	19	33 (Aug 13-19)	36	11	23
8 (Feb 19-25)	54	14	19	34 (Aug 20-26)	37	12	24
9 (Feb 26-M4)	50	13	18	35 (Aug 27-S2)	38	13	25
10 (Mar 05-11)	48	13	18	36 (Sep 03-09)	41	15	27
11 (Mar 12-18)	46	12	18	37 (Sep 10-16)	42	17	28
12 (Mar 19-25)	45	12	17	38 (Sep 17-23)	44	18	28
13 (Mar 26-A1)	43	12	17	39 (Sep 24-30)	48	19	29
14 (Apr 02-08)	42	11	17	40 (Oct 01-07)	53	20	29
15 (Apr 09-15)	41	11	17	41 (Oct 08-14)	55	21	29
16 (Apr 16-22)	41	11	17	42 (Oct 15-21)	64	22	29
17 (Apr 23-29)	41	11	17	43 (Oct 22-28)	71	22	29
18 (Apr 30-M6)	39	11	16	44 (Oct 29-N4)	80	22	28
19 (May 07-13)	39	11	16	45 (Nov 05-11)	87	22	28
20 (May 14-20)	38	11	15	46 (Nov 12-18)	91	22	28
21 (May 21-27)	37	11	15	47 (Nov 19-25)	95	21	28
22 (May 28-J3)	37	11	15	48 (Nov 26-D2)	97	21	27
23 (Jun 04-10)	37	10	15	49 (Dec 03-09)	96	21	27
24 (Jun 11-17)	37	10	15	50 (Dec 10-16)	92	20	25
25 (Jun 18-24)	37	10	16	51 (Dec 17-23)	89	19	25
26 (Jun 25-J1)	37	10	16	52 (Dec 24-31)	86	19	24

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