USE OF DEGREE-DAYS TO TIME AERIAL SPRAYING IN WEST-CENTRAL COLORADO

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ABSTRACT. Seasonal fluctuations in *Culex* and *Aedes* were followed from 1984 to 1987 using degree-days (°Days). The annual population maxima of a "mosquito season" can be predicted. *Culex* first becomes a problem at about 1,550 °Days and disappears at 2,675 °Days. *Aedes* are present at 525 °Days, experience a midsummer decline at 900 °Days, then resurge at 2,400 °Days to mostly disappear at 2,700 °Days. This timing appears to work in the arid western valley of Grand Junction, Colorado, due to the dependence by the mosquito on breeding sites related to local irrigation systems, which are dry in the winter and rehydrated at the same time each year.

INTRODUCTION

There has been great interest by botanists in using temperature to predict harvest time for crops because the relationship between temperature and plant growth is closely related. Due to this direct commercial benefit, botanists made early attempts to find methods of measuring the daily accrual of heat. Candolle (1855) was the first to compute daily heat units by summing the mean temperature for each day. The heat unit he used was called "day-degrees." This general concept has been modified frequently by botanists but has not been extensively utilized to predict invertebrate development.

Growth and development of invertebrates also depends on ambient temperature, which can be used to predict time of emergence of invertebrate pests. Nelson (unpublished data, 1982) has utilized degree-days to predict codling moth, *Carpocapsa pomonella*, emergence in orchards. The emergence of the apple maggot, *Rhagolatis pomonella*, was predicted by a degree-day model (Laing and Heraty 1984). Whitfield (1984) examined degree-day accumulation and the development of sugar beet rust maggots, *Leucania unipuncta*. However, it does not appear that degree-days have been used to predict mosquito population dynamics. In this paper we have examined seasonal *Culex* and *Aedes* population growth using degree-days and have applied them to aerial spray programs. Aerial spraying is now timed on both degree-days and field monitoring based on the findings of this paper.

MATERIALS AND METHODS

In this study we used the following formula for degree-days (Nelson, unpublished data, 1982):

$$\left[\frac{\text{D max. (°F)} + \text{D min. (°F)}}{2}\right] - 50\text{°F} = \text{°Days}$$

D max. and D min. are the daily maximum and minimum temperatures in the Fahrenheit scale; °Days are the daily accumulated heat units in degree-days. The computer program used to generate the degree-day table was programmed in Fahrenheit because the weather bureau reports temperatures in Fahrenheit and it was tedious to constantly convert to metric. The lower threshold for development was set at 50°F since it seemed consistent with diapause termination in the literature for mosquitoes and other insects. The upper threshold was 88°F. Degree-days were then determined using the data in Table 1 beginning on March 1 of each year. Mosquito trapping begins around the first of May due to seasonal availability of employees.

Degree-days for the years 1983 and 1984 were taken from tables generated in a local codling moth study (Nelson, unpublished data, 1982). Degree-days for 1985–87 were calculated using daily weather data from the National Atmospheric and Oceanic Administration Weather Service at Walker Field Airport in Grand Junction, Colorado.

The Redlands Mosquito Control District is located in a large valley in west-central Colorado. Two major river drainages, the Colorado and the Gunnison rivers, join at the southeastern edge of the valley and proceed west as the Colorado River. Along the south edge of the river numerous housing subdivisions have been built on the bluffs above the river. At one time the area was an agricultural center, but many of the fields and orchards are now small hobby farms with poorly managed pastures and gardens. There is a large flood plain along the river, and numerous canyons drain irrigation water from the pastures and lawns. The sandy soil also allows the water from lawns to percolate down to bedrock and seep out at the base of the bluffs. Although the area is a typical southwest desert, the river and irrigation create numerous breeding habitats for mosquitoes.

Mosquitoes were trapped one night a week using CDC-4 light traps baited with dry ice.

Table 1. Table of degree-days used to calculate degree-days in west-central Colorado. The lower threshold is 50°F and the upper threshold is 88°F.

Maximum Temps. (°F)	Minimum temperatures (°F)																										
	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88
118	21	22	22	23	23	24	24	25	26	27	28	28	29	30	31	32	32	34	35	35	36	36	37	37	37	38	38
116	21	22	22	23	23	24	24	25	26	27	27	28	29	30	31	31	32	33	34	35	35	36	36	37	37	38	38
114	21	21	22	22	23	23	24	25	26	26	27	28	29	30	31	31	32	33	34	34	35	36	36	37	37	38	38
112	21	21	22	22	22	23	24	24	25	26	27	28	29	30	30	31	32	33	34	34	35	36	36	37	37	38	38
110	20	21	21	22	22	23	23	24	25	26	27	28	28	29	30	31	32	33	33	34	35	36	36	37	37	38	38
108	20	20	21	21	22	22	23	24	25	26	27	27	28	29	30	31	32	32	33	34	35	35	36	37	37	38	38
106	20	20	21	21	22	22	23	24	24	25	26	27	28	29	30	31	31	32	33	34	35	35	36	37	37	38	38
104	19	20	20	21	21	22	22	23	24	25	26	27	28	29	30	30	31	32	33	34	34	35	36	37	37	38	38
102	19	19	20	20	21	21	22	23	24	25	26	27	27	28	29	30	31	32	33	34	34	35	36	37	37	38	38
100	19	19	19	20	20	21	22	22	23	24	25	26	27	28	29	30	31	32	32	33	34	35	36	36	37	38	38
98	18	19	19	19	20	21	21	22	23	24	25	26	27	28	29	30	30	31	32	33	34	35	36	36	37	38	38
96	18	18	19	19	20	20	21	22	23	23	24	25	26	27	28	29	30	31	32	33	34	35	35	36	37	38	38
94	17	18	18	18	19	20	20	21	22	23	24	25	26	27	28	29	30	31	32	33	33	34	35	36	37	38	38
92	17	17	17	18	18	19	20	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	37	38
90	16	16	17	17	18	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	36	37	38
88	15	16	16	16	17	18	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
86	14	15	15	15	16	17	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
84	13	14	14	15	15	16	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34		
82	12	13	13	14	14	15	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32			
80	11	12	12	13	13	14	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30				
78	11	11	11	12	12	13	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28					
76	10	10	10	11	11	12	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26						
74	9	9	9	10	10	11	11	12	13	14	15	16	17	18	19	20	21	22	23	24							
72	8	8	8	9	9	10	10	11	12	13	14	15	16	17	18	19	20	21	22								
70	7	7	8	8	8	9	9	10	11	12	13	14	15	16	17	18	19	20									
68	6	6	7	7	7	8	8	9	10	11	12	13	14	15	16	17	18										
66	5	5	6	6	6	7	7	8	9	10	11	12	13	14	15	16											
64	4	5	5	5	5	6	6	7	8	9	10	11	12	13	14												
62	4	4	4	4	5	5	5	6	7	8	9	10	11	12													
60	3	3	3	3	4	4	4	5	6	7	8	9	10														
58	2	2	2	3	3	3	3	4	5	6	7	8															
56	1	2	2	2	2	2	2	3	4	5	6																
54	1	1	1	1	1	1	2	2	3	4																	
52	0	0	0	0	0	1	1	1	2																		
50	0	0	0	0	0	0	0	0																			
48	0	0	0																								

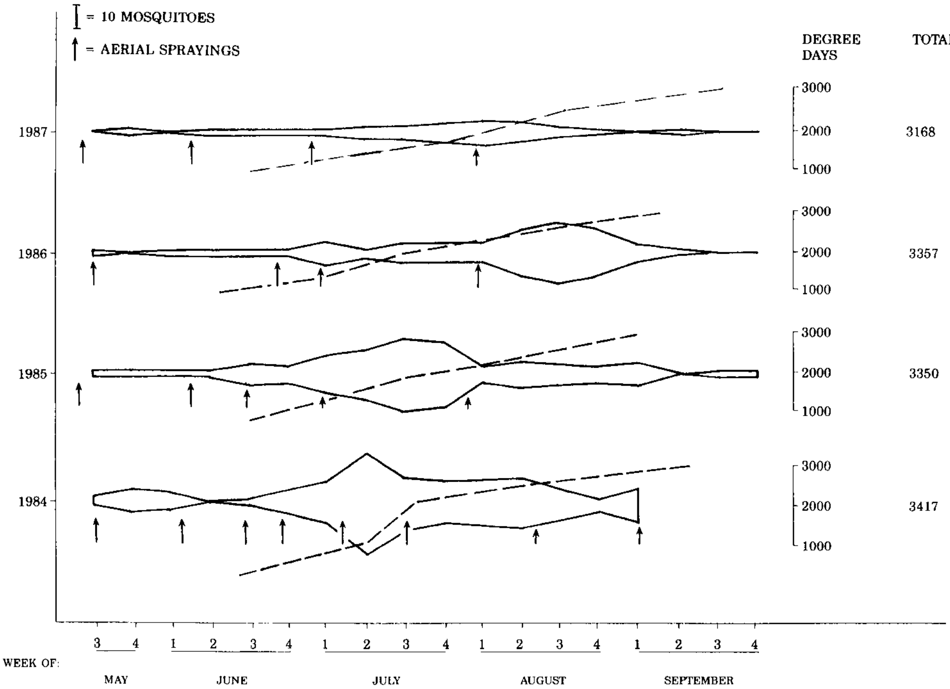

Fig. 1. Number of adult, female *Culex* per trap in 4 different years. The degree-days are also shown (dotted line).

Seven traps were used in 1987; previous years' data were obtained by using 4 to 6 traps. Most of these traps (3–6) were set around the perimeter of a mosquito control district and 2 others were set in areas lacking mosquito control. Only adult female mosquitoes were counted and identified to species. The total number of *Culex* and *Aedes* were divided by the number of traps set up on each date. The value obtained was rounded to the nearest whole number.

It was decided to use generic data instead of species for several reasons. Early data were collected by untrained student help and identification was often approximate. Identification of the *Culex* complex is especially difficult in this area since the differentiation between *Cx. pipiens* Linn. and *Cx. quinquefasciatus* Say is difficult because of hybridization between the species. Also, there are 5 species of *Aedes* and 4 species of *Culex* found in the study area, and on any given trap night one species or another may not be present. Finally, we were not attempting to study species characteristics but to develop a tool for timing our spraying program.

RESULTS

Four genera of mosquitoes are routinely collected in light traps in this area. The most prominent genus is *Culex*, which accounts for about 63% of the total. *Aedes* is also common, making up about 35% of the trap counts. The other 2 genera are *Anopheles* and *Culiseta*. *Culex tarsalis* Coq. and *Cx. pipiens* are present in about equal proportions. There are five species of *Aedes* present in the area, but *Ae. dorsalis* (Meigen) and *Ae. vexans* (Meigen) are the most abundant. *Aedes nigromaculis* (Ludlow), *Ae. idahoensis* and *Ae. trivittatus* (Coq.) make up the balance of the *Aedes* species.

Culex mosquitoes were present by the third week in May of each year except 1987. Numbers of *Culex* do not attain maximum numbers until late July through the third week of August. *Culex* populations decline quickly in September. Figure 1 shows *Culex* data in a butterfly graph with a plot of degree-days included for each year. The number of *Culex* trapped by date is indicated by the width of the box. There is an obvious July/August population peak. *Culex* populations begin to increase between 1,000 and 1,550 °Days. The *Culex* season usually declines after 2,675 °Days. The date of aerial larviciding is shown by arrows.

The number of adult, female *Aedes* trapped each week decline over the 4 years. *Aedes* were always present by mid-May. Populations fluc-

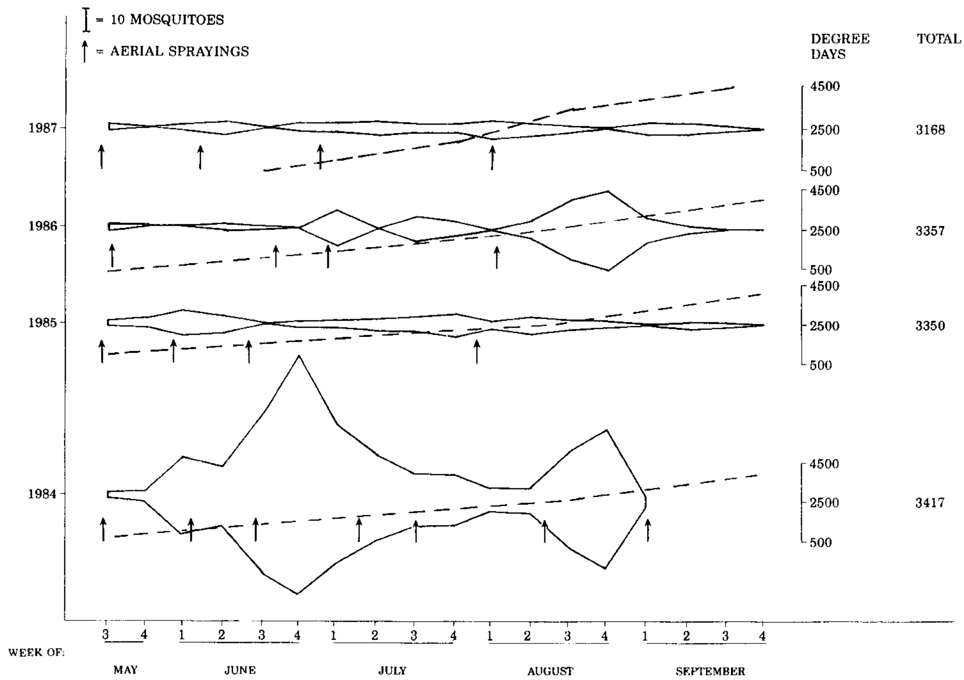

Fig. 2. Number of adult, female *Aedes* per trap in 4 different years. The degree-days are also shown (dotted line).

Table 2. Calendar dates for the beginning and end of adult *Culex* breeding seasons.

Year	1550 °Days (begin)	2675 °Days (end)
1984	July 12	Aug. 24
1985	July 8	Aug. 19
1986	July 8	Aug. 19
1987	July 15	Sept. 1

tuate but seem to be high in early summer and then again in August or September. Figure 2 shows this data in butterfly graph form. The early and late populations are easily seen in 1984 and 1986. *Aedes* generally only become abundant after the average accumulation of 525 °Days. These populations decline markedly after 900 °Days and peak again at about 2,400 °Days. *Aedes* disappear from traps quickly after 1,700 °Days. The dates of aerial spraying are shown by arrows.

Degree-days were measured each year from March 1 to October 1. The coolest year, in total number of degree-days, was 1987 with 2,892 °Days accumulated. The second coolest year was 1986 with 3,203 °Days, followed by 1985 with 3,269 °Days. The warmest year was 1984 with 3,417 °Days. Table 2 shows the calendar dates in each of these years on which 1,550 °Days and 2,675 °Days were first accumulated. Those values represent the average value of: 1) onset and 2) termination of the active breeding season for *Culex* spp., respectively. Table 3 shows similar data for *Aedes* species from 1985 and 1986.

DISCUSSION

Mosquito populations in west-central Colorado are seasonal and generally increase from May through late summer and then rapidly decline into October. This is due to severe winter temperatures and lack of breeding sites prior to March of each year when local canals are filled for agricultural irrigation. Growth is seldom steady but rather occurs in a series of peaks and smaller declines. When plotted on a graph, this creates a jagged and skewed sigmoid curve. This pattern was documented in west-central Colorado as early as 1958 by Ogden and Marsden (1961).[1]

[1] Ogden, L. J. and E. Marsden. 1961. An appraisal of the Mosquito Problems in Mesa County, Colorado. USDHEW, Public Health Service, CDC, in cooperation with Colorado State Department of Health and Mesa County Department of Public Health.

Table 3. Calendar dates for the beginning and end of adult *Aedes* breeding seasons, 1985–87.*

Year	Season begins 525 °Days	Season ends 900 °Days	2nd season begins 2400 °Days	Season ends 2700 °Days
1985	May 26	June 13	Aug. 8	Aug. 20
1986	May 26	June 13	Aug. 9	Aug. 20
1987	June 5	June 20	Aug. 20	Sept. 2

* Four dates are shown since the population appears to peak at least twice each summer.

Culex and *Aedes* are multivoltine with overlapping generations. Each generation has its own separate degree-day tally and is independent of all other generations. Also, mosquitoes are usually dependent upon rains or other sources of flooding, and their appearance during a certain time of year is most often influenced by the timing of such events. However, in west-central Colorado mosquitoes are dependent upon breeding areas that develop due to spills and seepage from the local system of canals and ditches developed for agriculture. These are left empty in the winter months for maintenance and because of soil seepage and salinity problems. Consequently, breeding areas are restricted to the local river bottom until March of each year when the canals are filled. This results in the unique condition that all mosquito populations begin to develop at about the same time each year. Furthermore, high temperatures, low humidity and a gradual withdrawal of water from local, mature crops result in the decline of breeding areas at about the same time each fall. This led us to believe that local populations might be able to be tracked using degree-days.

By monitoring mosquito population and degree-days since 1982, we have been able to compare peaks of growth with calendar date and degree-days over several years. While populations have been observed since 1982, only data from 1984 to 1987 are presented in this paper. Earlier data were used for baseline information and served to generate the ideas for this study. Consistent mosquito control efforts have had an obvious effect on *Culex* populations over the past several years. This is illustrated in Figs. 1 and 2 by lessening of the width of each population area from year to year, and also by the delay in population peaks from mid-July to early or mid-August.

The 4-yr average degree-days for the onset of first *Aedes* mosquitoes is 525 °Days. This may be due as much to water availability as to temperature. Two prominent rivers intersect in the valley, the Colorado and Gunnison rivers, and the adjacent flood plain is often inundated in early May, due to spring snow melt in nearby mountains. Also, the fertile desert valley has an extensive system of irrigation which is dry in winter but is flooded, along with the fields, at about this same time. *Aedes* is a flood plain mosquito, depositing eggs and overwintering in damp soil. Hence, large populations emerge early in the summer.

The four-year average degree-days from the onset of the first *Culex* population peak is 1,550 °Days. This has fallen as early as July 8 or as late as July 15 during the years studied. *Culex* populations decline rapidly after 2,675 °Days. This generally occurred between August 19 and September 1, 1983. *Culex* females were collected after these dates but increases in population occur within these limits. *Culex* overwinter as adults, and therefore the populations must build gradually over the summer months. This seems to be dependent on temperature.

An encephalitis outbreak occurred in Mesa County in 1985, one of the warmest years of the four, but there was also an early onset date of mosquitoes. However, 1984 and 1986 also had early calendar dates for reaching 1,550 °Days. Neither of these characteristics appears useful in predicting encephalitis risks.

Degree-days accumulated more quickly in 1985 than in other years (see Figs. 1 and 2). While it appears that 1984 had a more rapid rise, 3,000 °Days did not occur until well into September. In 1985, 1,500 °Days had accumulated by early July and 3,000 °Days had accumulated by late August. If virus replication is also dependent on temperature, then early warm temperature would suggest encephalitis risk.

By monitoring degree-days on a daily basis, we can keep indirect track of the development of the mosquito. By calculating the mean degree-days accumulated on a daily basis, predicting the timing of the first mosquito hatch in areas of seasonal occurrence can be relatively accurate. Combined with field observations, it can aid in making management decisions such as the timing of aerial spraying. Notice that there were 8 aerial sprayings in 1984, 5 in 1985, and 4 in both 1987 and 1988.

The Redlands Mosquito Control District relies exclusively on larviciding. This is because the mosquito problem is seasonal and because spraying insecticides over housetops and the Colorado River is not environmentally sound. For larviciding to be successful, timing is essential since spraying before egg hatch or after pupation wastes time and money. Degree-days have proven to be a useful management tool in these circumstances. This is evident from the general reduction in the number of aerial sprayings required to achieve control. Spraying today is based upon combined surveillance and degree-day accumulations.

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