Irrigation Cycles, Mosquito Cycles, and Generations of Aedes Mosquitoes in Irrigated Pastures in California*

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INTRODUCTION

Mosquitoes in irrigated pastures in California have been a major reason for one of the most intensive large-scale insect abatement programs ever organized in the interest of public health and community welfare. The program has expended millions of dollars and has received such public commendation that the future will bring an extension of mosquito control to additional areas of California and neighboring States.

The advance of technical and scientific knowledge is falling behind the advancing desire on the part of the public for expanded and intensified mosquito control. In this field, the science of mosquito ecology has probably lagged farthest behind. Several reasons for this condition exist.

Firstly, the need for operational investigations on the ecology of irrigated pasture mosquitoes could not be recognized until after the need for mosquito abatement over large areas became recognized as important to the welfare of the people in California. Secondly, the control program had to establish itself in the financial systems of State and local governments as a continuing program before efforts could be turned to less well understood aspects of the science of mosquito ecology.

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There are several factors contributing to the present existence of a State investigation on the ecology of irrigated pasture mosquitoes: firstly, the almost complete lack of knowledge of many of the most fundamental aspects of the natural history of irrigated pasture mosquitoes; secondly, the ever-increasing demand for even greater efficiency in the control program; thirdly, the pending increase in irrigated acreage brought about by the Central Valley Project (1) which will subject the Great Central Valley to a predicted increase of one-third in total mosquito control problem area; and lastly, increased difficulties in maintaining the standard of control established for the California program.

The purposes of the present investigations, which began in July 1949, were to establish fundamental facts with regard to the natural history of irrigated pasture mosquitoes. The essential problems were to determine the mosquito species existing in a typical habitat, the relative species abundance, the number of irrigation cycles each year, the mosquito growth cycles, and the effect of temperature on the growth and activities of the irrigated pasture mosquitoes. Much of this basic information was obtained.

MATERIALS AND METHODS

For special study during the 1950 season an irrigated pasture of approximately 90 acres, located in Stanislaus County in T55, R9E, S9,†† was chosen. At one time this pasture, referred to herein as the Schaub Study Pasture, had been planted to Ladino clover and pasture grasses, but a large portion of the pasture was in poor condition at the beginning of observations in March 1950. The soil is Fresno series dry sandy loam underlaid

†† Through courtesy of the owner and of the Turlock Mosquito Abatement District, no control was done in this pasture during most of the study (the first 13 irrigations).

with an almost impermeable hardpan at depths of from 12 to 30 inches.

The pasture is an inverted L-shaped block of land located about 8 miles west of Turlock in the midst of an intensively-farmed area. At the time of the study it was surrounded by several different types of crops. It was bordered on the north by a watermelon patch and a corn field, and on the east by a settlement of about 20 inhabited farm houses and groves of eucalyptus trees. To the south, a small pump-irrigated rice field stood adjacent, fitting into the angle of the L and lying just to the east of another irrigated pasture. On the west, it was bordered by a State highway beyond which were a corn field and additional pasture land. The owner's house and barns were located in approximately the northwest corner of the pasture.

Most of the studies were conducted in a 50-acre section of the pasture which in turn could be divided into three areas. These were: (1) an 18-acre section just south of the farm buildings; (2) a 20-acre section centrally located; and (3) an area of approximately 10 acres located east of the 20-acre section and adjacent to the rice field. These sections were separated by irrigation ditches and were bordered by fences or fence posts.

Strip checks, which are level strips of land about 50 ft. wide bordered by foot-high earthen ridges, extended from east to west. Irrigation was started in the higher eastern end of the checks and was completed in sequence beginning with the most easterly sections of the pasture and progressing to the west as needed.

The pasture was kept under continuous observation from the beginning of irrigation in the spring to early September. Special attention was given to the central sections of the pasture where observation stations were established for regular daily visits.

A standard weather station type of structure was located in the central portion of the field and contained a hygrothermograph set for weekly records of temperature and humidity.

Irrigation as practiced by the farmer was dependent upon the schedule of delivery through the canal supply system of the local irrigation district. The farmer's field practices for handling this water were different for each irrigation but generally resulted in the flooding of certain low areas during each cycle. Usually about 12 to 18 hours was required for a complete irrigation of the pasture although the central 20 acres generally was flooded in about 6 hours.

Water maps were prepared to delineate the area covered after each irrigation. These maps were made about 24 to 36 hours after the irrigation had ceased so that preliminary drainage could occur and so that the fixed point after which the receding water must leave the checks by either percolation, absorption, transpiration, or evaporation could be ascertained. These maps coincided with the development of second stage larvae of *Aedes nigromaculis* (Ludlow) and with the beginning of control operations under certain circumstances.

Observation stations were set up in selected checks and daily records were made of the water depth, the temperature of the water and air, and the larval density in terms of the number of larvae taken per dip. Aquatic stages were collected from each station during each visit and were preserved for future identification of stage and species of the larvae and the genus and sex of the pupae.

A. nigromaculis, the most abundant species under observation, received a major portion of the attention during the study. For purposes of the study, cycles of growth for this species were arbitrarily determined to begin with the flooding of the field and to end with the emergence of adults. These two points in the life cycle of the species population were believed to be those which could be accurately determined and therefore would result in comparable data.

Records of adult mosquitoes were made by the use of the cloth flag counting method (2) during the day and of a light trap located near the pasture at night. These indexes to adult density and activity provide information for a better understanding of the natural history of *A. nigromaculis*.

RESULTS

Eighteen cycles of irrigation were conducted in the Schaub Study Pasture. A growth cycle of *Aedes* mosquitoes occurred at each irrigation. The length of the growth period shows close correlation with the temperature. At temperatures averaging above 85° F., a growth cycle of less than 5 days occurred. At temperatures between 75° F. and 80° F., three cycles were recorded requiring from 5.75 to 6.5 days. At 70° F. to 74° F., three cycles were recorded requiring 6.5 to 6.75 days. When the mean temperature was from 65° F. to 70° F., two cycles of 7 and 8.5 days were recorded. Two cycles of 9 and 10 days were recorded for temperatures averaging 60° F. to 65° F., and two cycles of 14 and 16 days were recorded for mean temperatures 57° F. and 54° F., respectively, (table 1).

Samples of larvae identified showed that *A. nigromaculis* amounted to 98.3 percent of the *Aedes* larvae collected and 86.9 percent of the total mosquitoes collected. *Culex tarsalis* Coquillett was the most common *Culex* and amounted to 90.5 percent of the specimens of that genus collected. This species accounted for 10.2 percent of the total types of mosquito larvae taken. *Culiseta inornata* (Williston), the only *Culiseta* collected in the larval stage, amounted to 0.3 percent of the total. The genus *Culiseta* occurred in only the first six cycles.

It was noted that for 676 *Culex* pupae collected there was an almost 50-50 ratio of males to females, while for 6,077 *Aedes* pupae collected there was a ratio of 46.6 males to 53.4 females. Examination of the data also indicated that the number of female *Aedes* pupae exceeded the number of male *Aedes* pupae collected in every case in which more than 200 *Aedes* pupae were collected; whereas the male pupae exceeded the females when fewer than 200 pupae were collected.

During the longest growth cycle (flooding of pasture to adult emergence) which consisted of 16 days from March 16 to March 31 inclusive, the following periods of time were required for each larval stadium: first, 3 days; second, 2 days; third, 2 days; fourth, more than 6 days. The pupal stage required 3 days. The shortest growth cycle studies occurred from June 29 to July 4, a total of 4.75 days. During this short cycle the following periods of time were required for each larval stadium: first, 24 hours; second, 12 hours; third, 24 hours; fourth, 36 hours. The pupal stage required about 24 to 36 hours.

In making these observations it must be noted that there was some overlap of stadia—some specimens reached the fourth instar while others were moulting from second to third. The major portion of each brood of *A. nigromaculis* larvae changed en masse from one instar to the next.

The relationship of two indexes to adult *Aedes* density is shown in table 2 in which flag counts and light trap counts are compared for 13 cycles of irrigation in the study pasture.

Table 1

Irrigation Dates (Hatching Date for "Aedes" eggs), Dates Adults First Emerged, Length of Growth Cycle in Days and the Mean of the Maximum, Minimum, and Mean Air Temperatures for the Period.

Cycle	Date Irrigated	Date Adults Emerged	No. days for Emergence	Mean of temperatures in °F.		
				Max.	Min.	Mean
1	March 16 (6 a.m.)	April 1 (a.m.)	16.0	67	41	54
2	April 6	April 20	14.0	70	44	57
3	April 20	April 29	9.0	78	43	61
4	May 3 (2 a.m.)	May 13 (a.m.)	10.0	76	44	61
5	May 13 (8 p.m.)	May 22 (a.m.)	8.5	84	48	66
6	May 25 (4 p.m.)	June 1 (a.m.)	6.5	93	56	75
7	June 5 (10 p.m.)	June 14 (8 a.m.)	8.5	78	49	64
8	June 17 (6 p.m.)	June 24 (a.m.)	6.5	87	53	70
9	June 29 (6-12 a.m.)	July 4 (a.m.)	4.75	107	64	86
10	July 11 (5-12 a.m.)	July 17 (a.m.)	6.0	96	60	78
11	July 23 (a.m.)	July 29 (p.m.)	6.5	91	55	73
12	August 3 (a.m.)	August 10 (noon)	6.75	87	53	70
13	August 15 (noon)	August 21 (a.m.)	5.75	100	58	79
14	August 26 (a.m.)	Sept. 1 (a.m.)	6.0	97	60	79
15	September 6	September 13	7.5	82	53	67
16	September 18	September 24	6.5	87	53	70
17	September 29	October 6	8.0	81	47	64
18	October 9	October 20	11.0	84	50	66

Table 2

PEAK ADULT INDEX OF FEMALE "AEDES NIGROMACULIS" (LUDLOW) FROM CLOTH FLAGS AND LIGHT TRAPS, SCHAUB STUDY PASTURE, TURLOCK, 1950.

Cycle No.	Date Adults Emerged	Peak Index			
		Flag Count		Light Trap 11	
		Date	Index	Date	Count
1	April 1	April 4	4.8	April 6	30*
2	April 20	April 25	0.7	April 24	32*
3	April 29	May 9	0.6	May 13	4*
4	May 13	May 20	0.4	May 13	4*
5	May 22	May 25	5.9	**	**
6	June 1	June 3	1.3		
7	June 14	June 17	14.7		
8	June 24	June 26	9.6	June 26	216
9	July 4	July 6	23.3	July 7	1,519
10	July 17	July 18	7.1	July 22	976
11	July 29	August 1	56.8	July 31	1,274
12	August 10	August 12	14.4	August 13	236
13	August 21	August 24	21.9	August 24	1,181

*Collections for 3-day periods.
**Collections destroyed by museum pests before identification.

Records of temperatures, shown in table 3 and table 4, indicate there is a difference between the water and air temperatures and that the surface and bottom temperatures vary with the depth of the water and the amount and type of vegetation present. For seven stations, varying from 4.5 to 9.5 in. in depth and showing a change in type and amount of vegetation, there was a difference of from 1° to 17° between the bottom temperatures and the surface temperatures of the water.

Daily fluctuation of air temperatures during the early part of July was found to be more than 40° F. From a low of about 64° F. which occurred about 5 a.m. each morning, the air temperature rose rapidly reaching more than 106° F. by 4 p.m. Water temperatures during the same period ranged from 77° F. to 108° F.

The need to have measurements of the volume and extent of water producing a brood of *A. nigromaculis* within the Study Pasture was met by carefully mapping a single check each morning during the tenth irrigation cycle. This check (Number 9) was mapped for 630 ft. of its length and for 57.5 ft. in width. This area was computed to be 36,225 sq. ft. (0.83 acres) of which 96.9 percent was flooded (table 5). Based on an estimated average depth, the volume of water amounted to 53,325 gal. This cycle required 6.0 days from flooding of the field to the first observed emergence of adults. On the morning of the sixth day only 10,368 sq. ft. of the original flooded area was still covered with water and that amounted to 9,720 gal. By the time the adult *Aedes* had all emerged, only about 10 percent of the check under observation was still flooded. Ten days after the irrigation of July 11 and two days before the field was reirrigated, only an estimated 397 gal. of water covered less than 3 percent of the ground area. This is further complicated by the fact that survival of the species is not indicated by remaining water. *Aedes* that are able to reach late fourth stage or pupae can sometimes survive on moist soil to finally emerge as adults after a short period of development.

DISCUSSION OF RESULTS

Results of these measurements indicate the complexity of the ecological problems involved. Each irrigation cycle is a potential source of increasing numbers of mosquitoes. A succession of species occurs with each irrigation, beginning with the *Aedes* and ending with the *Culex*. Although the dominant species is *A. nigromaculis*, *Aedes dorsalis* completes for that dominance during the cooler spring and summer months. In the Stanislaus County area where the studies were conducted, the production of 18 irrigation cycles does not necessarily indicate the produc-

Table 3

RECORDS OF WATER TEMPERATURES, AIR TEMPERATURES, AND DEPTHS AT SELECTED STATIONS IN THE SCHAUB STUDY PASTURE, JULY 1, 1950

Station Number	Temperatures Air	Water Surface	Water Bottom	Hour of Day (PM)	Depth of Water (Inches)
6A	101	104		1:45	3.50
17A	96	105		1:00	2.50
19A	96	92		12:50	7.25
E23A	100	94		2:10	2.75
13A	97	95	89	1:10	5.25
W. Ditch at 12A	98	94	85	1:15	9.50
9A	98	96	79	1:20	6.75
10A	98	102	100	1:30	4.50
7A	98	101	100	1:35	4.50
W. Ditch at 6A	101	97	89	1:50	5.00
E12C	100	100	89	2:00	4.75
Mean (Last 7)	98.5	97.8	88.7		5.73

Table 4

RECORDS FOR THE POOL OF STANDING WATER IN THE WEST END OF TWO CHECKS IN THE SCHAUB STUDY PASTURE, JULY 1

Station Number	Water Depth (Inches)	Temperatures Air	Water Surface	Water Bottom
Check 7 - Open Water, No Vegetation, Alkali Bottom, 1:35 p.m.				
1	1.00	98	103	103
2	5.00	98	102	100
3	0.50	98	103	103
A	4.50	98	101	100
Check 13 - Short Ladino Clover Covering Bottom Emergent When Water is 1 to 2 in. Deep				
1	1.75	97	103	100
2	3.50	97	101	98
3	5.00	97	101	96
4	1.00	97	104	104
A	5.25	97	95	89

tion of the same number of generations of *A. nigromaculis*. Other factors complicate this problem. The unknown factors involved in the production, conditioning, and maturation of *Aedes* eggs must be considered. The egg-to-egg generation is the most difficult to measure since dormancy may affect the number of eggs that will hatch. This dormancy results in the partial overlapping of hatches of eggs deposited by several preceeding generations with each flooding of the pasture, and causes explosive increases in the adult mosquito population. This is further complicated by the fact that as the temperature increases, the rate of growth in the aquatic stages is speeded up which results in a shorter egg-to-egg cycle. The shortening of this cycle increases the

Table 5

Measurements of Amount of Water Covering a Single Check (Number 9)
Schaub Study Pasture, Stanislaus County, Calif., 1950. (Total Area of Check Estimated at 36,225 Sq. Ft.)*

Date	Days After Irrigation	Area Covered By Water (Sq. Ft.)	Percent of Area Covered By Water	Volume of Water (In gallons)	"Aedes" Emergence
July 11	0	35,110	96.9	53,325	Hatched
12	1	26,505	73.2	43,897	
13	2	25,209	69.6	33,870	
14	3	21,645	59.8	28,410	
15	4	18,101	50.0	21,502	
16	5	**	**	**	
17	6	10,368	28.6	9,720	Emergence Began
18	7	5,184	14.3	4,665	
19	8	3,564	9.8	2,452	Completed
20	9	1,782	4.9	1,110	
21	10	972	2.7	397	

*Table prepared from data collected by William E. Trimmingham, Entomological Assistant.
**No record made on this day.

number of mature eggs available for hatching with each irrigation. The synchronization of the egg-to-egg cycle and of the irrigation cycle may occur in midsummer. Large increases in the adult populations of *A. nigromaculis* occurred in July, August, and September during the 1950 season.

Control measures differ in various parts of the Central Valley of California where irrigated pastures are found. In general, larval control is directed at the second to fourth stage larvae of *A. nigromaculis*. As the summer temperatures rise, the growth rate of these stages is speeded up until the time available for larviciding may be cut in half. In some cases the timing becomes so critical that the operator may have only a single day to reach flooded areas where the water area is small enough that it can be treated economically and still control the larvae before pupation occurs.

SUMMARY

1. Each of eighteen irrigation cycles produced a corresponding growth cycle of *Aedes* mosquitoes in a selected study pasture.

2. The dominant species in irrigated pastures is *Aedes nigromaculis* (Ludlow). *Cultex tarsalis* Coquillett is the dominant *Culex* and occurs in areas of poor drainage and standing water.

3. The growth rate of aquatic stages of *A. nigromaculis* varied with the temperature. As the mean temperature increased, the rate of growth increased and the time spent in various instars decreased.

4. In the pastures studied, peaks of *A. nigromaculis* production occurred during the months of July, August, and September.

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