EFFECT OF ENVIRONMENTAL FACTORS ON BITING ACTIVITY OF *AEDES VEXANS* (MEIGEN) AND *AEDES TRIVITTATUS* (COQUILLETT)[1]

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As is characteristic of animals in general, adult mosquitoes alternate periods of activity and quiescence. The activity period, which is largely spent in flight, seems to be initiated by the exogenous factor of light intensity, especially in the case of crepuscular species.

Although periodic in nature, the activity pattern of adult mosquitoes can be shortened, delayed, or even postponed altogether by such additional exogenous forces as temperature, relative humidity, air movement, and barometric pressure. Abnormalities in light intensity produced by extra heavy cloud cover, the appearance of a bright moon, or the occurrence of an eclipse are capable of further modifying this pattern.

Although a number of general observations have been made relating the effects of environmental factors to the activity of adult *Aedes vexans* (Meigen) and *A. trivittatus* (Coquillett), no precise field measurements of their influence on the biting behavior of these species have been made. The study reported here was designed to accomplish such measurements.

We acknowledge with sincere appreciation the generosity of Dr. and Mrs. T. A. Brindley in permitting us to use the yard of their home as a study site.

MATERIALS AND METHODS. The general area used for this investigation was a wooded tract of approximately 20 acres on the west side of Ames, Iowa. This woodland was basically an oak-hickory community with typical floodplain vegetation along the creek that flowed through it. The specific study site was in the backyard of a home situated at the edge of the woods. Several major larval habitats for *Aedes* and *Culex* mosquitoes existed in and near this area of woodland. Studies were carried out during the mosquito seasons of 1964 and 1965.

Mosquito population estimates were obtained, usually daily, during the study period by larval dipping surveys and adult sweeping catches around the aquatic sites actively producing mosquitoes. In addition, a New Jersey light trap was operated nightly at the specific study site.

Since it was already known (Barr 1958) that both mosquito species to be studied have an early evening activity period, this portion of the diel cycle was selected for the study period. Observations and collections were begun 45 minutes before sunset. The time of sunset was obtained from the Nautical Almanac (1964, 1965) and adjusted to local time. On nights used, observations and collections were continued for at least three hours, longer if environmental conditions remained acceptable. The experimental time was divided into consecutive 15-minute periods, with the fourth period beginning at the moment of sunset.

Mosquito flight activity was measured at the specific study site by a New Jersey light trap equipped with a 40-watt frosted bulb and, in 1965, additionally by a 16-inch upright suction trap. In both cases, the trap killing-jars were changed at the end of each 15-minute period. Biting activity was measured by taking a 5-minute biting catch during the first half of each 15-minute period. Only the mosquitoes

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that were biting or probing on both arms and one leg from the knee to the ankle of the collector were taken. The same individual made all the catches. A six-celled flashlight equipped with Corning glass filters, as described by Murphey and Darsie (1962), was used for illumination in the after-dark catches.

Temperature, relative humidity, light intensity, barometric pressure, and wind velocity readings were taken at the midpoint of each 15-minute period. All the instruments, except the light meter and the barometer, were placed on top of a table about 3 feet above the ground. Temperature readings were made with a Taylor [3] maximum-minimum thermometer. An Abbeon [4] relative humidity indicator was used to measure the relative humidity. Wind velocity was measured with a 4-inch 8-blade Biram [5] anemometer. A Taylor brass-base barometer calibrated to local altitude was used to measure barometric pressure. A Weston [6] Model 756 light meter with a sensitivity of 0.1 footcandle was used to measure changes in light intensities. A modification of the technique of Dyson-Hudson (1956) was used to measure reflected light. In 1965, incident light was also measured by turning the photoelectric cell toward the sky. All light readings were taken at the one-foot level.

A carefully planned movement routine was followed throughout each experiment so that all results could be safely compared. Furthermore, the path between the three catching sites was maintained free of tall vegetation so that mosquitoes would not rest in these areas and then subsequently be stirred into activity by movement of the observer along the path.

Lower than normal precipitation during the summers of 1964–1965 resulted in smaller than desired catches of *A. vexans*. On the other hand, catches of *A. trivittatus* were satisfactory.

Results. The results obtained for *A. vexans* and *A. trivittatus* are discussed separately.

Activity of Aedes Vexans

Time of Peak Activity. Figure 1 illustrates graphically the total numbers (186) of *A. vexans* collected in the suction trap per period in 1965. Flight activity in the 45 minutes before sunset (periods one through three) was low. However, beginning at sunset with period four, a marked increase occurred. This continued through the fifth period. Thereafter, flight activity was again at a low level. It is belived that the activity measured by the suction trap was largely random, although the possibility that the motor of the trap might have an attractant effect cannot be entirely ruled out.

Biting count totals per period are shown in Figure 2 (in all, 331). This activity also began to increase in the fourth period. Here, however, the peak occurred during periods five through seven, with 54 percent of the total catch being taken during these 45 minutes. Nearly the same results were obtained in 1964, with 51 percent of the total catch coming from these three periods. Biting activity started to decline noticeably in the eighth period, the time when complete darkness normally occurred. During the last hour of the collections, biting activity was maintained at a constant level of about one-fourth of the rate reached in the three peak periods. These results agree generally with the observations on *A. vexans* biting activity by Beadle (1959) and Thompson (1964).

A comparison of Figures 1 and 2 discloses that flight activity, as measured by the suction trap, began its evening increase about 15 minutes earlier than biting activity. A partial explanation of this could be that the evening flight activity perhaps began in the latter half of the 15-minute period following sunset and, since the biting catch was made in the first 5 minutes of each period, this increase in activity did not actually demonstrate itself until

[3] Taylor Instrument Company, Rochester, New York.

[4] Abbeon Supply Company, 179–15 Jamaica Avenue, Jamaica 32, New York.

[5] David Instrument Manufacturing Company, Baltimore, Maryland.

[6] Daystrom Incorporated, Weston Instrument Division, Newark, New Jersey.

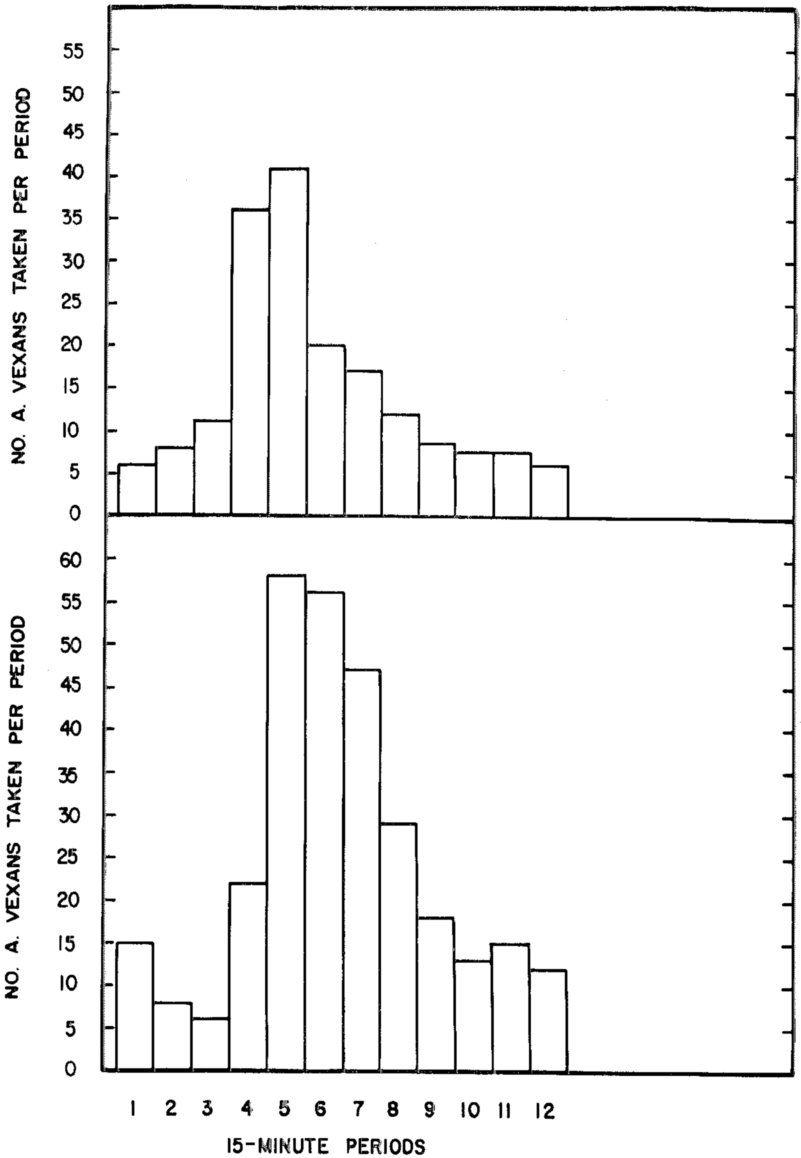

FIG. 1 (top).—Total *A. vexans* females taken per period in the suction trap in 1965.
FIG. 2 (bottom).—Total *A. vexans* taken biting per period in 1965.

the fifth period. The suction trap ran continuously throughout each 15-minute period and would accordingly show an increase in flight activity that occurred at any time during the period.

Another factor that could have contributed to the earlier activity at the suction trap was the movement pattern of this mosquito. If *A. vexans* females move in short waves of flight from their daytime resting places in the shrubs to the lawn areas, as proposed by Barr (1958), then they would have encountered the suction trap before they reached the biting count station. This type of a movement pattern would also partially account for the earlier decrease in activity at the suction trap as compared with the activity at the biting count station (compare Figures 1 and 2).

CORRELATION OF ACTIVITY WITH ENVIRONMENTAL CONDITIONS. The results already presented have shown that the evening peak periods of biting and flight activity of *A. vexans* are coordinated with a specific time in relation to sunset. It was next desired to determine what effects, if any, various environmental factors had on this activity period. The data for the 16 sets of observations conducted during the 1965 peak population period, May 12 to June 30, were used for this purpose. In all, 80 percent of the total *A. vexans* taken in the standard biting collections in 1965 were from this 8-week period. Specific environmental factors considered were light intensity, relative humidity, temperature, barometric pressure, and air movement. The first three of these are graphically compared with flight and biting activity in Figure 3.

TABLE 1.—Numbers of *A. vexans* collected per period in the light trap in 1964 and 1965.

	15-minute periods												
	1	2	3	4	5	6	7	8	9	10	11	12	Total
1964	..	..	..	..	2	3	8	6	4	9	3	8	43
1965	..	..	..	3	11	9	8	10	3	5	11	4	64
Total	..	..	..	3	13	12	16	16	7	14	14	11	106
			Sunset										

A linear regression test was made with the data from the suction trap and the biting collections to determine if the biting activity of this mosquito could be predicted from the flight activity as sampled by the suction trap. This analysis was significant at the 1 percent level, indicating that when large numbers of *A. vexans* were taken in the suction trap, the biting rate was also likely to be high.

Table 1 presents the total numbers of *A. vexans* taken per period in the light trap from May 12 to September 1, 1964, and 1965. An examination of these data shows that activity, as sampled by the light trap, was erratically distributed over the periods after the light came on. Because of the small numbers of this species taken in the light trap in either year, it is difficult to determine if attraction to the light measured any fluctuation in activity. At any rate, no peak response time is evident.

LIGHT INTENSITY. As noted previously, biting activity began to increase immediately after sunset (in the fourth 15-minute period). The reflected light intensity at the mid-point of this period averaged 2.0 foot-candles (range 0.6–11.7). The average light intensity at the mid-point of the fifth period, the first period of high biting activity, was 0.12 foot-candle (range 0.0–3.0). The light intensities, both reflected and incident, were on all but one occasion (0.2) below 0.10 foot-candle in the sixth period. These results agree with the observations of Beadle (1959) who found that a foot-candle reading of about 0.2 usually corresponded to the first "wave" of crepuscular mosquitoes, including *A. vexans*. Similarly, Thompson (1964) working in Wisconsin reported that the peak time of *A. vexans* biting activity occurred between 30 and 45 minutes after sunset.

The release of evening flight activity by a decrease in light intensity may also provide another explanation for the previously discussed fact that flight activity as measured by the suction trap began earlier than did biting activity. Since the suction trap was located in the woods, its location would naturally undergo an earlier decrease in light intensity than would the biting collection station, which was out in the open.

TEMPERATURE. The average temperature per period for the 16 sets of collections examined in detail ranged from 63.4–69.2° F. (Figure 3), and the maximum range for periods in which mosquitoes were taken was 58–75° F. Considering the *A. vexans* collected in all light trap, suction trap, and biting catches during 1965 (a total of 583), we find that 96 percent of them were taken between temperatures of 60–80° F., with a total range of 56–84° F.

Since the number of *A. vexans*-positive catches was larger in some portions of the total temperature range than in others, simple catch totals per temperature range unit would not accurately represent the effect of temperature upon the activity being measured. Consequently, the average numbers of *A. vexans* taken per positive 15-minute catch was computed for both temperature and relative humidity (Table 2). Although the numbers of *A. vexans* taken were too small to permit precise determinations of truly optimal temperature and relative humidity ranges for biting, flight, and light visiting activity, a general impression of these factors can be gained.

RELATIVE HUMIDITY. The average relative humidity per period for the 16 sets of observations examined in detail ranged from 61.5–76.7 percent (Figure 3), and the maximum range for periods in which mosquitoes were taken was 28–98 percent. Considering the *A. vexans* collected in all light trap, suction trap, and biting catches during 1965, 93 percent of them were taken between relative humidities of 40 and 90 percent. The average numbers taken per positive catch in 10 percent units of relative humidity are presented in Table 2. Here again the mosquito totals taken were too small to give more than the range of relative humidity over which this species is active.

WIND. Activity of *A. vexans* was depressed by winds over 2.0 m.p.h.

BAROMETRIC PRESSURE. A barometric

TABLE 2.—Average numbers of *A. vexans* taken per 15-minute period * in all catches in 1965.

Type of Collection	Temperature F°							Total # Positive 15-min. periods	Total mosquitoes involved
	55–59	60–64	65–69	70–74	75–79	80–84	85–89		
Biting catch	1.3	1.3	3.6	1.9	1.5	1.3	0.0	136	331
Suction trap catch	2.0	1.8	2.9	2.5	1.6	1.3	0.0	110	186
Light trap catch	1.5	1.2	1.4	1.1	1.0	0.0	0.0	53	66
								Total:	583

Type of Collection	# obs. periods	Relative Humidity %							
		20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99
Biting catch	136	2.0	1.8	1.9	1.8	1.9	3.7	2.3	1.2
Suction trap catch	110	1.5	1.3	1.4	3.8	1.6	2.2	1.3	1.1
Light trap catch	53	0.0	0.0	1.5	2.0	1.3	1.3	1.1	1.0

* Only those periods in which mosquitoes were taken are included here.

pressure reading was taken during each period of all experiments. The barometric change that took place in any one 3-hour period was quite small, the greatest drop occurring in one regular experiment being only 0.03 inch. No difference in activity was evident at any of the different barometric pressures encountered.

A. vexans ACTIVITY IN THE AFTERNOON. Three experiments were conducted in the afternoon during the peak population period of May and June to determine the amount of *A. vexans* activity at this time. The temperature range was from 75 to 83° F., and the relative humidity range was between 32 and 67 percent for the

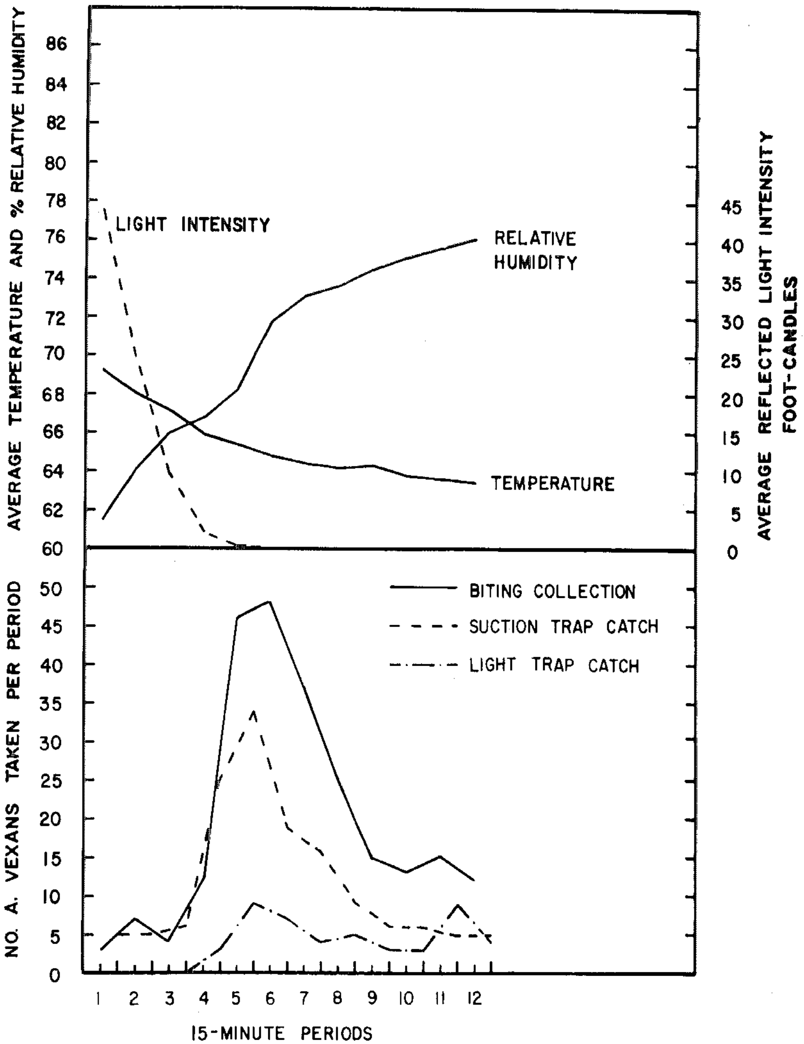

FIG. 3.—Numbers of *A. vexans* females captured in the biting collections, suction trap, and light trap in successive 15-minute periods during May and June 1965 with accompanying average reflected light intensity (foot-candles), temperature, and relative humidity values.

three experiments. Observations and collections were made for a total of 12.5 hours. Only eight adults were taken in the biting collections and only one in the suction trap. These results demonstrate that *A. vexans* was not active in the afternoon. However, this mosquito did bite in the woods during the daytime if its resting places were disturbed.

A. vexans ACTIVITY IN THE AUTUMN. A brood of *A. vexans* was produced in mid-September 1964. Four experiments

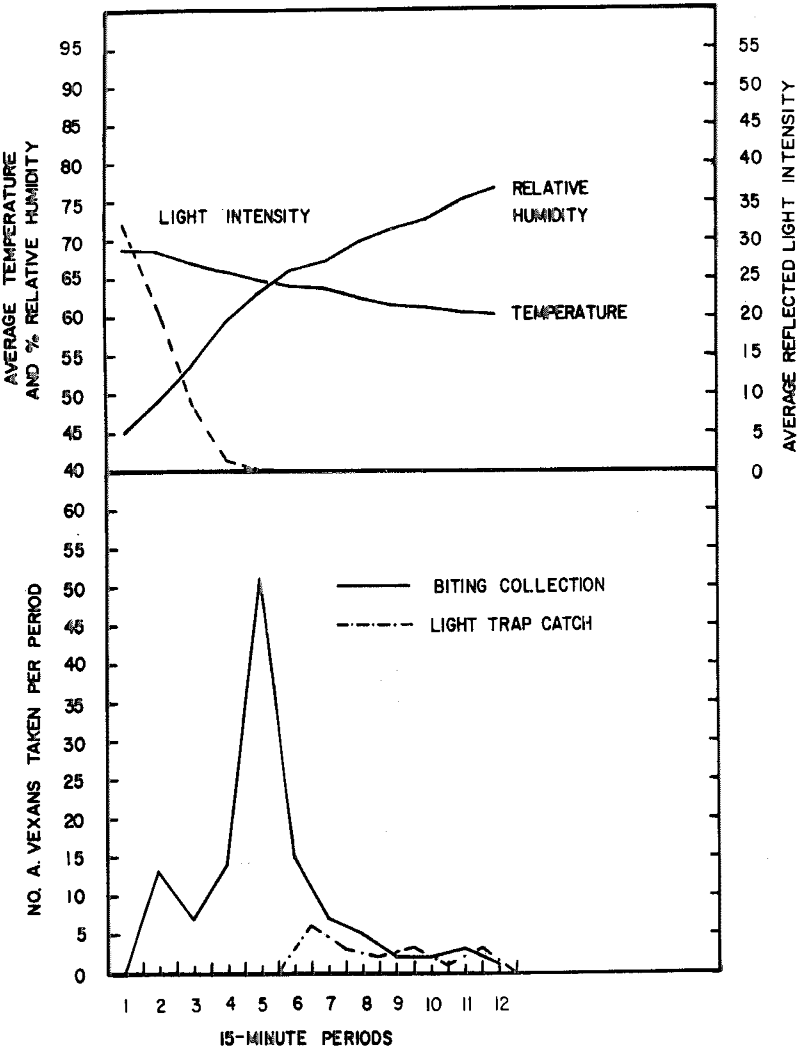

FIG. 4.—Numbers of *A. vexans* females captured per period in the biting collections and light trap during the autumn of 1964 with accompanying average reflected light intensity (foot-candles), temperature, and relative humidity values.

were conducted between September 13 and October 1 to determine if the biting activity pattern in the autumn differed from that observed in late spring and in the summer. The data collected are presented graphically in Figure 4.

The peak period of activity in the autumn was the fifth, just as was the case with the summer activity. However, 83 percent of the *A. vexans* taken biting in the autumn were collected in the first 90 minutes of the experiments, whereas only 56 and 55 percent were taken during this time in the summer collections of 1964 and 1965, respectively. It is probable that this earlier activity in the autumn was because of the earlier decrease in light intensity at this time of the year. A comparison of the data reveals that the average reflected light intensity during the autumn was lower than that for the corresponding periods during the summer. This earlier decrease of light intensity in the autumn was, of course, expected. That the biting activity of *A. vexans* was also earlier in the autumn supports the idea that the activity of this mosquito is regulated to a great extent by the light intensity.

Activity of Aedes Trivittatus

Time of Peak Activity. In 1965, 1,902 *A. trivittatus* were taken in biting collections during the regular 3-hour experiments. All these were captured after the week of June 3–9 when the first brood of this mosquito emerged. The distribution by period of these biting individuals is illustrated in Figure 5. It can be seen that biting activity by *A. trivittatus* was quite high from the first through the seventh periods, with the peak period occurring during the first 45 minutes after sunset (periods 4, 5, and 6) and then decreasing rather rapidly after that. A similar pattern was obtained in 1964.

A. trivittatus activity as measured by the light trap during 1965 reached a peak in the sixth period (Figure 6). Although not shown here, this was also true in 1964. A total of 398 *A. trivittatus* were taken during the regular experiments in the suction trap in 1965. The peak periods of flight activity were the third, fourth, and fifth periods (Figure 7). Flight activity decreased sharply after the sixth period to a level about one-fourth as great as that in the previous six periods. As was the case with *A. vexans,* activity as measured by the suction trap occurred about 15 minutes earlier than did biting activity.

In both the biting and suction trap catches, *A. trivittatus* was highly active at the beginning of the regular experiments or 45 minutes before sunset (Figures 5 and 7). This is in marked contrast to *A. vexans* (Figures 1 and 2). To determine how early this mosquito was noticeably active, two experiments were conducted in the afternoon. These catches were begun 5½ hours before the regular starting time. Both were conducted for 4 hours and 45 minutes. Biting collections were made in the shade throughout the experiments from period −22 on, while the suction trap was in the shade only from period −12 on. Figure 8 illustrates the total numbers of mosquitoes captured per period by both collecting methods during the two experiments. That 49 of the 58 *A. trivittatus* captured in the suction trap were taken after it was enveloped in shade suggests that this mosquito was predominantly active only in the shade in the afternoon. These two experiments show that, although *A. trivittatus* does exhibit its peak activity during the crepuscular period, it is also very active long before sunset in shaded areas.

Correlation of Activity with Environmental Conditions. As in the case of *A. vexans,* the peak time of flight and biting activity of *A. trivittatus* occurs in the crepuscular period. Data were collected to determine to what extent this activity period was influenced by environmental factors. To obtain the most accurate analysis of the relation of the environmental conditions to the activity patterns of *A. trivittatus,* only the experiments conducted between June 11 and July 8, 1965 (the period of maximum abundance) were examined in detail. The mosquito catches and the environmental data for experiments conducted during this period are illustrated in Figure 9.

LIGHT INTENSITY. An examination of Figure 9 indicates that biting activity of this mosquito increased to its peak time between the middle of the third period and the middle of the fourth period. The average reflected light intensity was 11.1 and 2.6 foot-candles at the mid-points of

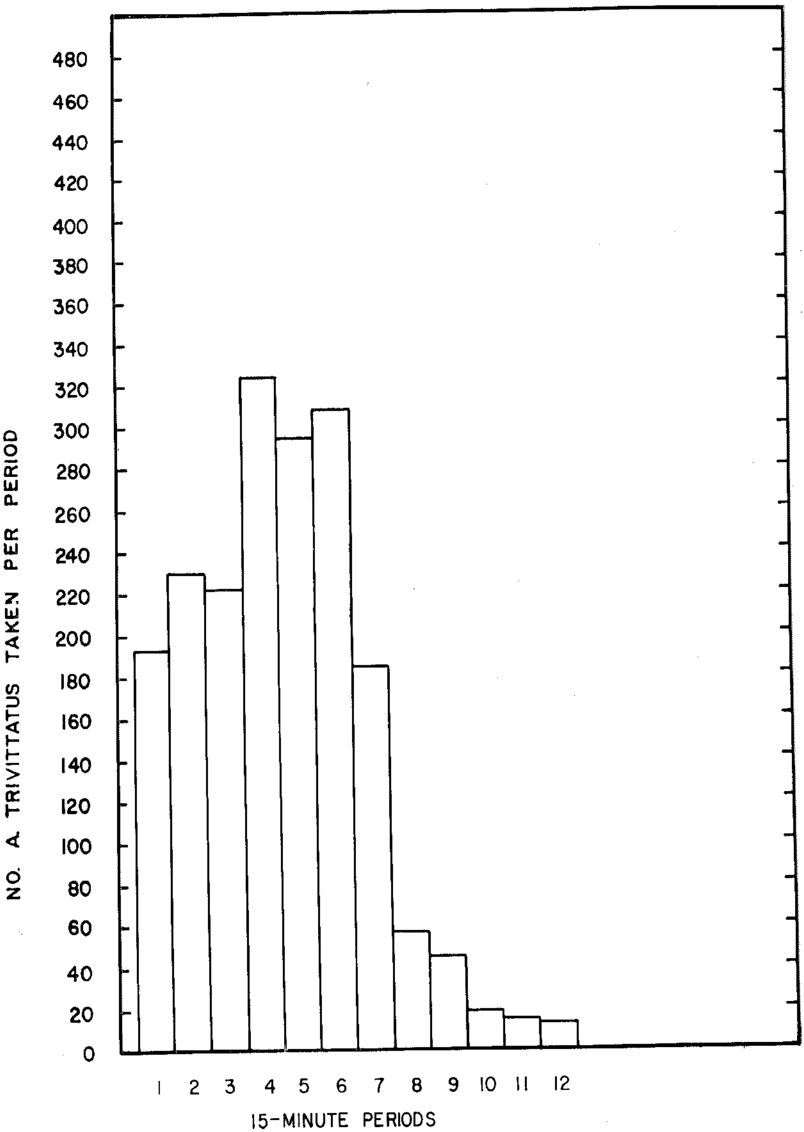

FIG. 5.—Total *A. trivittatus* taken biting per period in 1965.

these two periods respectively. Biting activity continued at this high level for the next three periods, during which time the average reflected light intensity was decreasing from 2.6 to 0.00 foot-candles. Biting activity decreased very quickly after the sixth period and was occurring at a relatively low level from the eighth period on. This sudden decrease in activity after the eighth period and the relatively high

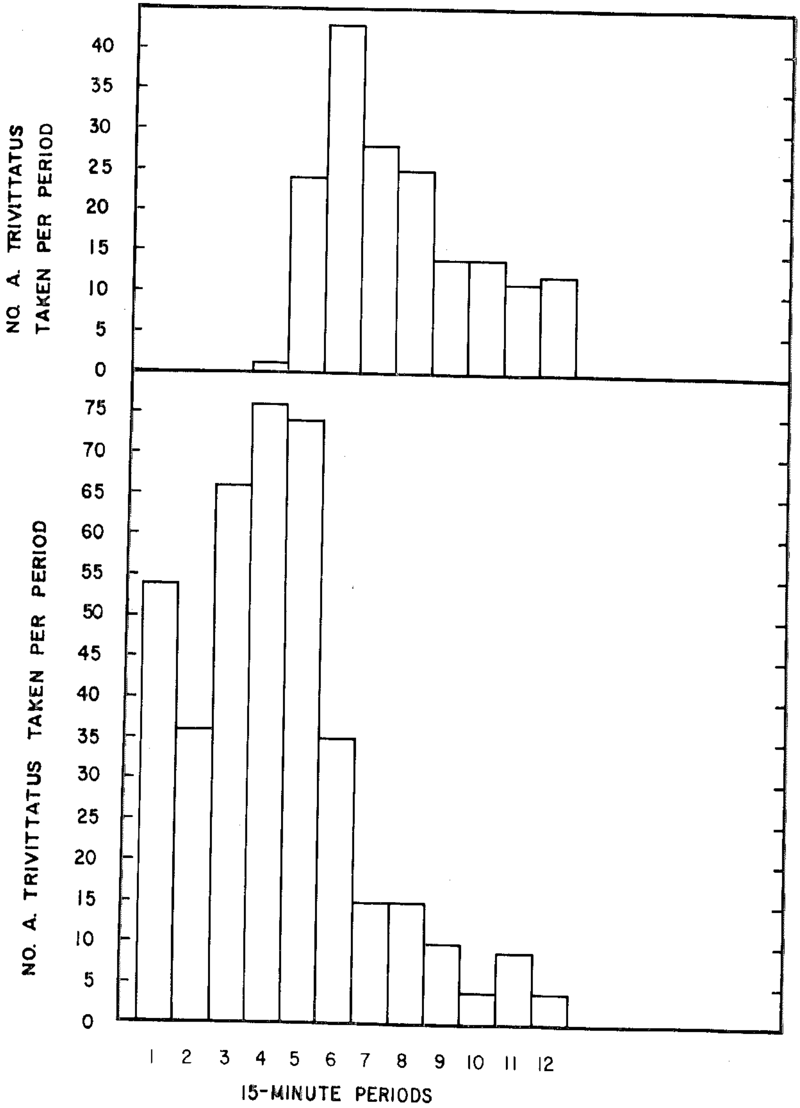

FIG. 6 (top).—Total *A. trivittatus* females taken per period in the light trap in 1965.
FIG. 7 (bottom).—Total *A. trivittatus* females taken per period in the suction trap in 1965.

activity during the afternoon suggest that this mosquito is basically active in the late diurnal and crepuscular periods and not active in the nocturnal period.

TEMPERATURE. The average temperature per period for the eight experiments examined in detail ranged from 66.8–72.9° F. (Figure 9), and the maximum range for periods in which mosquitoes were taken was 59–80° F. Considering the *A. trivittatus* collected in all light trap, suction trap, and biting catches during 1965 (a total of 3098), 95 percent of them were taken between temperatures of 65–84° F., with a total range of 58–86° F.

As was also done for *A. vexans*, the average numbers of *A. trivittatus* taken per positive 15-minute catch were computed for both temperature and relative humidity (Table 3). Unlike the case with *A. vexans*, sufficient numbers of *A. trivittatus* were taken to permit at least rather adequate determinations of optimal temperature and relative humidity ranges for biting activity.

RELATIVE HUMIDITY. The average relative humidity per period for the eight sets of observations examined in detail ranged from 59.1–73.6 percent (Figure 9), and the maximum range for periods in which

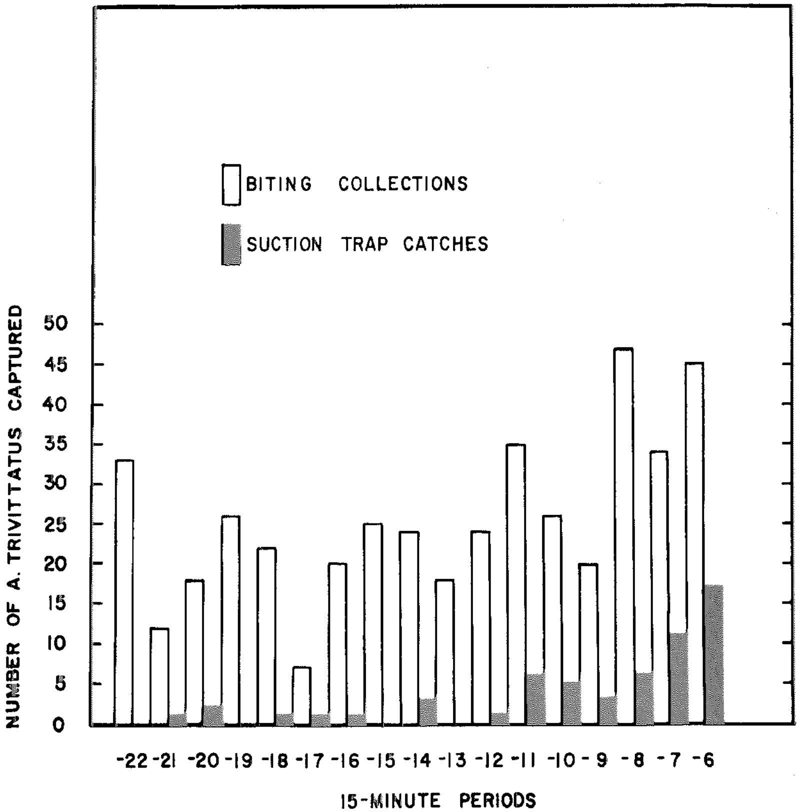

FIG. 8.—Numbers of *A. trivittatus* females taken per 15-minute periods in the biting collections and suction trap during two afternoon experiments in 1965.

mosquitoes were taken was 35–98 percent.

Considering the *A. trivittatus* collected in all light trap, suction trap, and biting catches during 1965, we find little significant preference exhibited for any relative humidity between the maxima observed, 32 and 98 percent (Table 3).

WIND. Winds with a velocity of over 2.0 m.p.h. seemed to have a suppressing effect on the activity of *A. trivittatus.*

BAROMETRIC PRESSURE. As stated previously, no significant pressure drops occurred during any of the experiments. As a result, no opportunity occurred for de-

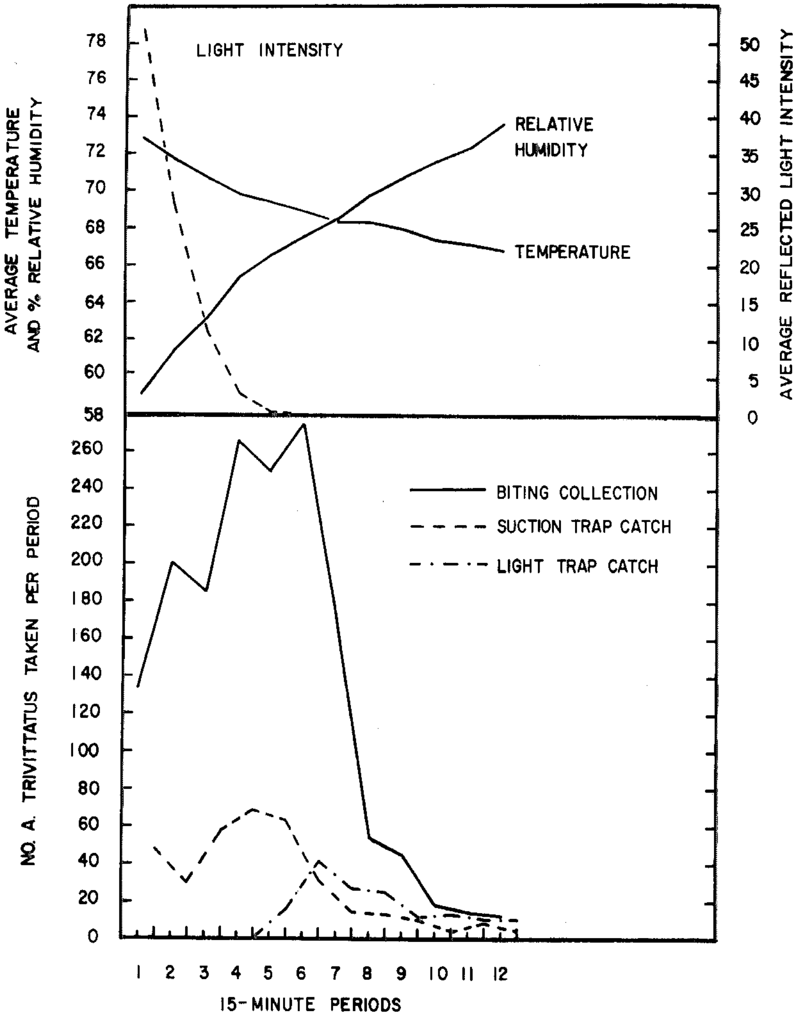

FIG. 9.—Numbers of female *A. trivittatus* captured in the biting collections, suction trap, and light trap in successive 15-minute periods between June 11 and July 8, 1965 with accompanying average reflected light intensity (foot-candles), temperature, and relative humidity values.

termination of the possible effects of pressure changes on mosquito activity.

DISCUSSION

Determination of the environmental conditions under which adult mosquitoes are maximally active has an important control implication. Insecticidal fogs are widely used in adult mosquito control. Because of the fineness of fog droplets, the bulk of them will not impinge upon stationary objects but will do so if the target has an additive velocity of its own. Therefore, in adulticiding with fogs it is necessary that the fogging be accomplished when the mosquitoes to be controlled are active.

Based upon the results of this study, the best time to apply insecticides for the control of adult *A. vexans* and *A. trivittatus* is in the evening within a period beginning no earlier than 30 minutes before sunset and extending no later than one hour after darkness; and at times when the temperature is above 60° F., the relative humidity is between 40 and 90 percent, and the wind velocity is no greater than 5 m.p.h. (preferrably less). Presumably a similar burst of activity is initiated by the dawn crepuscular period, but a study of this period was not included in this project.

Because it is commonly said that biting flies are more active before a thunderstorm, we thought that the decreasing atmospheric pressure normal at such a time might possibly be a contributing factor in the initiation of adult mosquito activity. This thought was strengthened by the work of Haufe (1954) who found that a rise or fall of 7 mm in atmospheric pressure greatly increased the activity of laboratory reared *A. aegypti*. Accordingly, barometric pressure was measured every 15 minutes throughout each experiment. However, the changes in pressure during any one experiment were so slight and the numbers of captured mosquitoes generally so low that no relationship was found between barometric pressure changes and activity of *A. vexans* and *A. trivittatus*.

Wolfe and Peterson (1960) noticed that an increase in blackfly activity was associated with a thunderstorm and suspected that the increase in activity might have been caused by a change in atmospheric pressure. Upon investigation, however, they found that only a slight change in atmospheric pressure had occurred and decided that the increase in blackfly activity was associated instead with a decrease in light intensity. This could equally well apply to mosquitoes.

Because of the recent demonstration

TABLE 3.—Average numbers of *A. trivittatus* taken per 15-minute period * in all catches in 1965.

Type of Collection	Temperature F°							Total # Positive 15-min. periods	Total mosquitoes involved
	55–59	60–64	65–69	70–74	75–79	80–84	85–89		
Biting catch	0.0	1.2	10.2	15.2	6.0	8.0	1.0	226	2446
Suction trap catch	0.0	3.8	3.5	5.6	3.0	2.3	0.0	118	479
Light trap catch	1.1	2.0	2.9	3.5	1.7	1.0	0.0	63	173
								Total:	3098

Type of Collection	Relative Humidity %								
	20–29	30–39	40–49	50–59	60–69	70–79	80–89	90–99	...
Biting catch	0.0	12.8	13.2	17.6	13.6	11.6	4.1	10.3	...
Suction trap catch	0.0	3.8	3.9	4.2	10.6	3.2	2.1	5.5	...
Light trap catch	0.0	0.0	3.0	1.0	2.0	3.9	1.5	2.8	...

* Only those periods in which mosquitoes were taken are included here.

(Bidlingmayer 1964) that adult mosquito activity is stimulated by moonlight, a cadmium sulfide-cell light meter, sensitive to very low light intensities, was used to measure moonlight on those occasions when its presence coincided with biting catches. However, mosquito catches would have had to be far more numerous and larger than they were to obtain significant results.

SUMMARY

This study was designed to investigate in the field the effects of light intensity, temperature, relative humidity, air movements, and barometric pressure upon the blood-seeking behavior of *Aedes vexans* and *A. trivittatus*.

We found that maximum flight activity and subsequent blood feeding by avid *A. vexans* females was initiated when decreasing light reached an approximate intensity of 2.0 foot-candles and that it subsided to a rather constant low level after about 60 minutes of darkness. Although numbers of females taken were not adequate to determine precisely the optimal maxima, extensive flight and blood-seeking activity occurred between temperatures of 60 and 80° F. and relative humidities of 40 and 90 percent. Wind velocities of over 2.0 m.p.h. depressed both flight and biting activity of *A. vexans*.

A. trivittatus became active at a higher light intensity than did *A. vexans*. For example, the biting activity of *A. trivittatus* was quite high in shaded areas in the afternoon (with light intensities from 500 down to 95 foot-candles), whereas *A. vexans* exhibited very little biting activity during this time. The greatest increase in *A. trivittatus* biting activity occurred in the 8 minutes immediately before sunset (June-July) during which time the average reflected light intensity was decreasing from 11.1 foot-candles. Thus, the maximum increase in *A. trivittatus* biting activity occurred about 15 minutes earlier than that of *A. vexans*. Biting activity by *A. trivittatus* subsided over 80 percent from the time of greatest activity by 45 minutes after darkness.

The numbers of *A. trivittatus* taken were sufficient to give adequate indication of optimal maxima, and it was found that extensive flight and blood-seeking activity occurred between temperatures of 65 and 84° F. and relative humidities of 32 and 98 percent. As with *A. vexans,* wind velocities of over 2.0 m.p.h. depressed both flight and biting activity.

No correlation was found between changes in barometric pressure and the activity of either *A. vexans* or of *A. trivittatus*.

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