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DEPENDENCE OF CO_2-BAITED SUCTION TRAP CAPTURES ON TEMPERATURE VARIATIONS

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ABSTRACT. In order to provide better standardized CO_2-baited trap samples, the relationship between sample size and evening temperatures was studied. Adult mosquitoes were collected for 3 h centered on sunset by an automatic interval suction trap baited with CO_2 in the Upper Rhine Valley, Germany. *Aedes vexans* females were most abundant, and their blood-seeking activity showed a significant correlation with the evening's average temperature ($r = 0.76$, $P \leq 0.05$). A higher degree of correlation was obtained when the number of specimens caught was related to temperature indices ($r = 0.93$–0.98, $P \leq 0.01$). A regression equation indicates the lower temperature threshold for *Aedes vexans* was between 9 and 10°C. For each degree of increase in the average temperature index, it was estimated that a 5.5% greater number of mosquitoes would be trapped. An upper temperature threshold for this species was not observed at average temperatures ≤23°C. A relationship between catches of *Aedes rossicus* and *Aedes cinereus* and temperatures recorded at the site during the study was not found.

INTRODUCTION

Physiological needs (carbohydrates, blood, oviposition sites), habitat needs (resting, searching), terrain features (mass, pattern), and meteorological factors (light, temperature, humidity, wind), on their own and in combination, make unraveling the complex of factors that may influence the activity of an adult mosquito a delicate and difficult task.

Due to the complex influence of meteorological parameters on the behavior of adult mosquito species, it is usually difficult to assess the impact of single climatic factors. If changes in adult mosquito populations are to be measured in a more meaningful way, it is necessary to compensate for the variability in samples brought about by the influence of weather conditions. The impact of these weather factors upon mosquito activity and collections is of such an importance that it should not be overlooked.

Carbon dioxide-baited traps for monitoring mosquito populations are widely used in many mosquito surveillance programs. In general, daily trap samples for the desired period of time are added together and simply averaged. Straightforward mathematical techniques such as the Williams's mean and the 5-day moving mean are very helpful for interpreting mosquito trap data. The Williams's mean technique reduces the influence of a few very productive traps on the average of all the traps (Downing 1970) or can be applied when the pattern of daily biting activity is monitored (Jaenson 1988). The 5-day moving mean technique reduces the influence of meteorological fluctuations and is very useful in long-term monitoring projects when, for example, seasonal peaks of activity are to be recorded (Downing 1970). However, when the trapping period covers several days, weather changes alone can lead to much greater discrepancies.

Although illumination is an independent factor and light intensity is of paramount importance for blood-searching behavior (Bidlingmayer 1985, Jaenson 1988), our experience suggests that temperature is a major influence on the biting activity of some mosquito species.

The objective of this study was to show that it is possible to quantify, on the basis of probability, that the number of *Aedes vexans* (Meigen) adults caught by CO_2-baited traps could be correlated to temperature changes during the sampling period. A modelling of the effect of temperature on adult mosquito catches would enable an extrapolation of short-term assessments, especially in case of sudden weather changes.

MATERIALS AND METHODS

Mosquitoes were sampled at the deciduous forest of Ketsch on the Rhine River island. The island is situated 16 km southwest of Heidelberg, Baden-Württemberg County, Germany (49°22′05″N, 8°31′21″E). The collecting site was shaded and located in a protected natural area, dominated by the following vegetation: *Salix alba, Salix purpurea, Populus canadensis, Rubus caesius, Urtica dioica,* and *Rorippa amphibia.* The mosquito-collecting device was a modified CDC-light trap, baited with dry ice. The so-called "interval suction trap" was equipped with 12 automatically rotating collection nets. The net rotating device was powered by a 6-V battery that provided automatic rotation of the nets and separated samples at half-hour intervals. The dry ice container (1 kg/trap/night) was placed below the suction fan. The fan entrance was placed 60 cm above the ground.

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Table 1. Number of mosquitoes captured in CO_2-baited traps and species composition at the Ketsch forest, Upper Rhine Valley, Germany (July and August 1991).

Species	July 24	July 25	July 26	July 27	July 28[1]	July 29	July 30	July 31	Aug. 1	Total number
Aedes vexans	109	49	77	74	61	165	127	39	86	787
Aedes rossicus	102	42	60	60	26	41	48	31	44	454
Culex pipiens	14	15	38	62	13	39	16	9	14	220
Aedes cinereus	31	9	17	14	6	46	11	14	12	160
Aedes sticticus	6	4	2	1	4	10	7	2	2	38
Culiseta annulata	1	—	1	4	—	—	1	1	1	9
Anopheles maculipennis	—	—	3	—	1	2	—	—	2	8
Mansonia richiardii	1	—	—	—	—	—	—	—	—	2

[1] High winds. Data not analyzed.

Trapping was carried out on 9 successive days (July 24–August 2, 1991). Six samples were collected between 90 min before and after local sunset, which was at 2120 h on the first and 2105 h on the last day of collection.

Temperature was continously monitored by a hygrothermograph placed 0.6 m above the ground. During the 9 successive days, 3 species were collected in sufficient numbers to provide separate analysis of activity dependence on temperature. For each of the 9 trapping days, the temperatures of the 6 half-hour sampling periods were averaged. Further data analysis required comparison of the temperature of the monitored day with the temperature values of the previous day. This enabled us to obtain a temperature index (t_i), which was incorporated in the statistical evaluation.

$$t_i = \frac{t_n}{t_{n-1}} t_n,$$

in which t_n = temperature of the monitored day and t_{n-1} = temperature of the previous day.

Indices were calculated for each day's average temperature (3 h), and also for each of the temperatures of the 6 half-hour periods. When both current and previous temperatures are identical the value of the temperature index is 1, whereas when the temperature of the previous day is lower, the temperature index is greater. If the opposite is true, the index is smaller. The starting point of the analysis in this paper was the 2nd monitoring day, as the temperature index for the first day was not obtained.

Mosquito catches were expressed as ratios. Each day's catch ratio was calculated by dividing the number of mosquitoes in each of the samples obtained during the evening trapping period by the largest sample caught. The total number of mosquitoes caught during the 3-h period on each successive night was correlated (Pearson's correlation coefficient) with average temperatures, average temperature indices, and half-hour interval indices.

RESULTS

Mosquito number and species at the trapping site were typical for the Rhine flood plains. Of the 8 species caught, *Aedes vexans* was the dominant species: 787 (46.9%) specimens were trapped (Table 1). It was followed by *Aedes rossicus* Dolbeskin, Gorickaja and Mitrofanova, *Culex pipiens* Linn., *Aedes cinereus* Meigen, *Aedes sticticus* (Meigen), *Anopheles maculipennis s.l.*, *Culiseta annulata* (Schrank), and *Mansonia richiardii* (Ficalbi) with relative abundances of 27.6, 13.1, 9.6, 2.3, 0.5, 0.5, and 0.1%, respectively. The number of specimens for *Ae. sticticus, An. maculipennis, Cs. annulata* and *Ma. richiardii* were too low for valid analysis and were excluded from the evaluation. *Culex pipiens* was represented by a large number of individuals, but because of continuous reinfestation from nearby breeding sites it was also excluded.

Temperatures ranged from 14.0 to 25.5°C during the study period. The lowest temperature value was recorded on July 25, 1.5 h after sunset; the highest was registered 1.5 h before sunset on July 30 (Table 2). The average lowest and average highest daily temperatures of the experiment were recorded on these same dates and were 15.0°C (July 25) and 23.3°C (July 30). During the study, temperature declines during the evening ranged from 1°C (August 1) to 4.5°C (July 29).

The number of *Ae. vexans* caught during the 3-h sampling period was correlated with the average temperature for the period ($r = 0.76$, $P \leq 0.05$, Fig. 1). The relationship between activity and temperature is even stronger when the number of mosquitoes trapped is related to the average temperature index ($r = 0.93$, $P \leq 0.01$, Fig. 2).

Table 2. Temperature (t) variations during the 9-day trapping period (Ketsch, July and August 1991).

Temperature factor	July 24	July 25	July 26	July 27	July 28	July 29	July 30	July 31	Aug. 1
3-h average t (°C)	16.8	15.0	16.5	17.7	20.6	22.6	23.3	18.2	18.6
3-h average t index	—	13.4	18.2	18.9	24.1	24.7	23.9	14.2	19.1
Sunset t (°C)	16.8	15.0	16.0	17.0	20.3	22.5	23.0	18.0	18.5
Sunset t index	—	13.4	17.1	18.1	24.1	25.0	23.5	14.1	19.0

Extrapolating from the regression equation ($y = 0.5217 + 0.0551x$, Fig. 2), the lowest activity temperature threshold for *Ae. vexans* would be 9.5°C. An upper threshold was not observed within the recorded temperature range. The regression equation indicates that for each 1°C increase in temperature index value there was a 5.5% increase in the sample size.

To simplify the evaluation of activity with temperature dependence (without recording the temperatures for the entire evening period and calculating an average temperature value), we examined the correlation of the temperature index of each sampling interval (any of the 6 within a trapping period) with the sample size. All of the 6 half-hour trapping interval temperature indices showed a consistent relationship with the sample size ($r = 0.95$–0.98, $P \leq 0.01$). However, the most appropriate temperature index for analysis proved to be the temperature measured at sunset ($r = 0.98$, $P \leq 0.01$). The activity of *Ae. rossicus* and *Ae. cinereus* was not correlated either with average temperature or with any of the temperature indices during the 7 monitored days.

DISCUSSION

Setting aside physiological needs (only bloodseeking females were collected), habitat needs, and features of the terrain (the sampling site remained the same for the entire period monitored), meteorological factors were a major influence on the sample size obtained. As changes in the light intensity during sunset are generally independent of other meteorological factors (Bidlingmayer 1985), it was simple to exclude this influence by setting the sampling period to conform with local changes in sunset time. It was then assumed that the mosquitoes were exposed to similar changes in light intensity during all 9 trapping days.

Wind velocity was below measurable levels during 8 of the 9 days monitored and therefore in this study the effect of wind on the mosquito

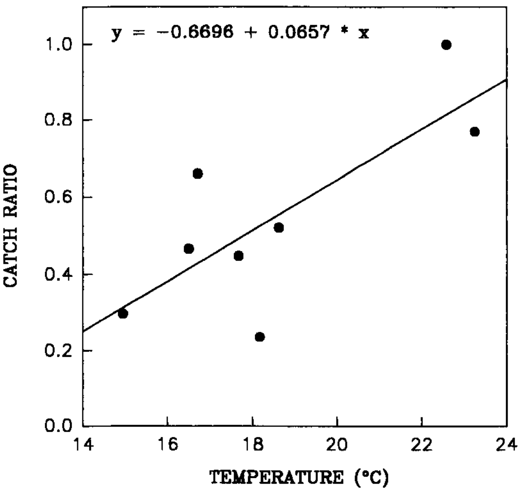

Fig. 1. Dependence of the CO_2-baited trap catch ratio on the average temperature in *Aedes vexans* females.

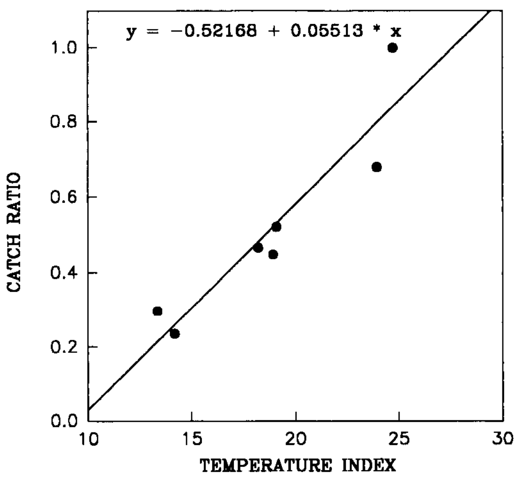

Fig. 2. Dependence of the CO_2-baited trap catch ratio on the average temperature index in *Aedes vexans* females.

flight path could be neglected. Due to the short study period the lunar cycle was not of substantial influence and therefore not considered in the evaluation.

Influence of temperature is one of the strongest factors that modify the daily activity of adult mosquitoes. *Anopheles* sp. in Pakistan bit mainly in the evening during the cool season and later in the night during the warm season (Reisen and Aslamkhan 1978). A similar pattern was found for *Anopheles merus* Dönitz in South Africa; the biting peak shifted to the first half of the night when the minimum temperature dropped to 16°C (Sharp 1983). Differences in evening temperatures had a marked effect on the pattern of biting activity in *Aedes sollicitans* (Walker). Read and Adames (1980) found in Panama that dipterans with nocturnal biting activity (*Lutzomyia panamensis* (Shannon) and *Mansonia dyari* Belkin, Heinemann and Page) had their peak of activity when the temperature was 22 and 24°C, whereas diurnal mosquitoes [*Haemagogus lucifer* (Howard, Dyar and Knab)] were most active at temperatures between 24 and 32°C. These authors concluded that these temperatures may stimulate biting activity in individual species at whatever time they occur.

Although the activity of *Ae. vexans* was correlated with the average temperature of the sampling period ($r = 0.76$, $P \leq 0.05$, $1 - r^2 = 0.42$), a considerable proportion of the variation in sample size was brought about by other factors despite the stability of other relevant parameters (relative humidity, wind speed, dispersal). Sudden day-to-day temperature changes can generate dramatic fluctuations in sample size. In order to determine whether females presumably involved in blood-seeking would respond to a temperature increase/decrease between 2 successive peaks of activity, the temperature value of the preceding day was considered. Such an approach was also tried by Dow and Gerrish (1970) and Read and Adames (1980) who included the relative humidity and evaporation rate of the previous day in their evaluations. When the average temperature index was correlated with the catch ratio, a significantly stronger relationship was obtained ($r = 0.93$, $P \leq 0.01$). This indicated that 86% of the variation in sample size was accounted for by the temperature index and the remaining 14% by the influence of other factors.

The temperature at which blood-seeking flights cease was not directly determined because of the relatively high temperatures typical for the end of July. In any case, the regression equation indicates that in the Upper Rhine Valley the lower temperature threshold for activity in *Ae. vexans* is approximately 9°C. During human biting collections in the Danube River Valley, mosquitoes were sampled between 5 and 32°C, but *Ae. vexans* was found only in collections from 9°C and above (Petric 1989[3]). For the same species in Florida, Bidlingmayer (1985) estimated the lower threshold temperature to be 7°C, but in view of the possibility that the 30% decrease observed in flight activity could represent the upper arm of a sigmoid curve he suggested that the lower threshold probably lies between 7 and 12°C. He also found that the upper temperature threshold for *Ae. vexans* is between 16 and 18°C, and that catches of individuals involved in food-seeking flights declined by 10% for every degree of decrease in temperature. Only 2 of the 7 days monitored in the present study had an average temperature >20°C. As the day with highest t_i is that on which the maximum number of mosquitoes was caught, it seems that the upper threshold for *Ae. vexans* lies above 23°C. For each degree of increasing t_i, the number of trapped mosquitoes increased by 5.5% (similar increase gradients were found for the average and the sunset temperature indices). Using the definition of lower and upper temperature thresholds given by Rudolfs (1925), that they actually represent the temperatures at which the first and the last individuals of a population could be engaged in flight, both thresholds then literally outline the limits of a normal curve. It is then probable that within this temperature range a sigmoid curve would be more appropriate to present the biting activity–temperature relationship.

In respect to *Ae. rossicus,* no temperature dependence was found in the range of temperatures that were recorded in the study site. The upper temperature threshold for the species is around 18°C, with no increase in abundance at higher temperatures.

It is not known whether *Ae. cinereus* is a crepuscular or a diurnal biter. Jaenson (1988) found that the peak activity of *Ae. cinereus* in pastures was at sunset, whereas in the forest this species was diurnal. C. J. Boase (unpublished data) states that in Hungary, *Ae. cinereus* has variable patterns of biting behavior. In a 3-year study, Petric (1989[3]) found that *Ae. cinereus* did not prefer any particular time of day for its biting activity.

Further studies that take a variety of meteorological factors into account over a more extended time period are needed to elucidate the flight behavior of the various mosquito species in detail.

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[3] Petric, D. 1989. Seasonal and daily biting activity of some Vojvodina (YU) mosquitoes (Diptera: Culicidae). Ph.D. Thesis. Faculty of Agriculture, University of Novi Sad, Yugoslavia.

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