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Atmospheric Stimulation of Man-biting Activity in Tropical Insects[1]

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ABSTRACT

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Data collected in the tropical forest of the Bayano River Basin, Republic of Panama, during the years 1973 through 1978 are used to test the hypothesis that there may be atmospheric stimulation which influences biting activity in haematophagous insects and this may be used to predict the probability of man being bitten by these insects. The data show that although some biting may occur over a wide range of temperature and dew point temperature, the maximum biting activity occurs in narrow ranges of these variables. There is a seasonality in the pattern of insect biting and the monthly rainfall patterns. During the period January through June, when about 25% of the annual rain has occurred, there is an 80% probability of being bitten by a mosquito while from July through December there is an 80% probability of being bitten by a phlebotomine in this tropical forest.

Introduction

The Republic of Panama commenced construction of a hydroelectric dam early in 1972 on the Bayano River about 70 Km east of the Pacific entrance to the Panama Canal. Subsequently, there was inundation of 300 Km² of tropical forest as a man-made lake was created up river from the dam site. As a result of this flooding, there were drastic ecological changes affecting the flora and fauna of the area. Three natural periods divided the investigation into a period of pre-impoundment 1972 through 1975, impoundment 1976 and 1977, and 1978 the first year of post-impoundment. The physical changes that occurred during these three periods were very apparent. In 1974, in the lower portion of the watershed near the field station there was a complete cutting of the forest up to the level at which the waters were expected to rise. In this area the only uncut forest was on a high ridge overlooking the river where the field station was located. This site was known as Altos de Majé and as Isla Majé after flooding. It consisted of about 20 Km² of untouched forest at the junction of the Bayano and Majé Rivers. Flooding began in February, 1976 and the man-made lake continued to grow in size and finally reached stabilization late in 1977.

In 1976, as flooding progressed, the water surface in the lower Bayano Lake near the island of Majé became covered with an aquatic fern *Azolla* (Hydropteridales, Salviniaceae). Early in this period this fern like water plant covered the lake as if it were a green rug and later in the year the color turned to red. In 1977 the lake was covered with large floating patches of water lettuce *Pistia* (Spathiflorae, Araceae) which moved from the north to the south side of the lake daily in response to water currents and the winds. By midsummer in 1978, the *Pistia* was under control and largely confined by log dams to the areas where the Bayano and Majé Rivers entered the man-made lake.

The Bayano River Basin was a huge natural laboratory in which insect-borne disease ecology could be examined. The working hypothesis was: There may be atmospheric stimulation which influences biting activity in haematophagous insects and this can be used to predict the probability of man being bitten by these insects in the tropical forest. The assumptions are: a) throughout most of the year the variation of air temperature and rainfall permit conditions which are wet and warm within the forest, b) these conditions are favorable for large populations of some insect vectors at different times of the year, c) the other environmental factors are favorable for large insect populations as physical conditions change in and around the forest. The insect enters the natural ambient micro-climate and bites man. The only control we had was the location of the host, as the temperature, wind, rain, and humidity were controlled by nature in a pre-flooding and post-flooding climate. The most abundant mosquito and phlebotomine species collected during 1973 and 1974 in the forest of Panama preferred narrow ranges of temperature and vapor pressure when engaged in man biting activity. Those species that were primarily canopy biters were also found near the forest floor given the same conditions of temperature and moisture using man as live bait during collections (Read *et al*. 1978).

Heavy rain showers may affect the distribution of insect populations in a forest area. In a study of sandfly populations in a tropical forest of Panama it was shown that the principal environmental factor affecting immature stages of sandfly populations and species compositions in tree based habitats was that of protection from flooding during heavy rainfall (Rutledge *et al*. 1972). Dryness or water logging of the forest floor due to scanty or excessive rainfall seems to reduce adult sandfly densities by affecting immature stages (Chaniotis *et al*. 1971). In an area of Panama through which sylvan yellow fever passed there were substantial year to year fluctuations in rainfall and correspondingly great fluctuations in the densities of arboreal mosquitoes known or suspected as yellow fever vectors (Galindo *et al*. 1956).

Measurements

The main climate station was located on a ridge in the forest overlooking the watershed. The measurements at this location were representative of the top of the

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forest canopy and the free air flow above the forest. Daily measurements were taken of rainfall, evaporation, winds, and the maximum and minimum temperatures. Continuous measurements were made of the total incoming radiation, temperature and humidity. At a tower which is located about 500 m from the main camp daily measurements were made of the evaporation and rain within the forest. Maximum and minimum temperatures were measured at five different levels from the forest floor through the canopy (29 m). Biweekly insect collections were made at this tower on the forest floor (one m) level and mid-canopy level (23 m) using a single adult male as a collector at each level. Hourly insect collections and measurement of temperatures and wet bulb temperature were made throughout the 24 h period. All of the meteorological and insect data collected from 1972 through 1978 were processed and edited and placed on punched cards and tapes.

Results and Discussion

In our investigation all collections were made using man as live bait and it was assumed that these collections are representative of man biting activity. We looked for atmospheric stimuli that might initiate biting when a host was always present during the collections.

Some insects are either daytime or nighttime biters. Time of day also implies conditions of relative warmth and low relative humidity in the daytime and opposite conditions at night. Temperature, humidity, rain, and the other atmospheric parameters are real and physical variables that can be measured by man and sensed by the insects. The biting preferences of certain abundant species collected during the period October 1972 to January 1978 are shown in Table (1) along with the temperature and the temperature of the dew point measured when the biting activity was at a maximum. The range of temperature and dew point at which some man-biting activity occurred is also shown. The data are normalized (% of the total collected) so that the various species can be compared. The temperature of the dew point is usually high in the daytime and low at night. When the temperature of the dew point is equal to air temperature, condensation may occur. Detailed analyses which are on file in the reference library at Gorgas Memorial Laboratory indicate that the following are nighttime biters: Diptera, Ceratopogonidae, *Culicoides diabolicus* Hoffman; Psychodidae, *Lutzomyia pessoana* (Barretto), *Lutzomyia trapidoi* (Fairchild & Hertig), *Lutzomyia sanguinaria* (Fairchild & Hertig); *Lutzomyia panamensis* (Shannon); and *Culicidae Mansonia dyari* Belkin. The mosquito, *Haemagogus lucifer* (Howard, Dyar & Knab) is a daytime biter. Certain ranges of dew point temperatures and air temperatures appear to correlate well with maximum biting activities of the various insects. Maximum biting activity is defined as the greatest number of insects collected at any given two degree range of temperature or dew point temperature, using man as live bait.

Most of the nighttime biters show peaks of maximum biting activity when the dew point temperature is 20 to 22°C; however, *L. panamensis* shows maximum biting when the dew point temperature range is 22 to 24°C. Of the total number of *L. panamensis* collected, 96% were collected when the dew point temperatures were in the low range of 18 to 24°C and indicates the insect is a nighttime biter. On the other hand, *H. lucifer* also showed maximum biting activity when the dew point temperature range is 22 to 24°C. *H. lucifer* is a daytime biter, and 74% of these insects were collected when the dew point temperature was in the high range of 22 to 28°C.

Most of the nighttime biters show peaks of maximum biting activity when the temperature is 22 to 24°C. *L. panamensis* and *M. dyari* show peaks of maximum biting activity when the temperature is 24 to 26°C; however, 87% of the *L. panamensis* and 91% of the *M. dyari* were collected when the temperature was in the low range 20 to 26°C indicating these insects are nighttime biters. *H. lucifer* also shows maximum biting activity when the temperature was 24 to 26°C, but 85% were collected in the high temperature range 24 to 32°C indicating that this insect is a daytime biter. The data suggests that these temperatures and dew point temperatures may be atmospheric stimuli for maximum biting activity whenever they occur.

We examined rainfall amounts over the period 1973 through 1978. Unlike evaporation, temperature, or humidity, which are continuous, rainfall is a discontinuous physical parameter. Nevertheless, monthly rainfall does play an important role in the man biting activity of certain insect species. There is a seasonality in the monthly rainfall patterns and there is a seasonality in the pattern of insect biting. Figure (1) shows the cumulative percentage of mosquito and phlebotomine collections along with the cumulative percentage of annual rainfall in the years 1973–1977. This graph shows the correlation of

Table 1.—Temperature and dew point temperature when biting activity was at a maximum and the range of temperatures and dew point temperatures when the insects were collected.

Species	Temp. °C	Number	Temp. Range	% of Total	Dew Point °C	Number	Dew Point Range**	% of Total
Culicoides diabolicus	22–24	170,573	18–32	42	20–22	266,785	18–30	66
Lutzomyia sanguinaria	22–24	1,389	20–32	46	20–22	1,990	16–28	66
Lutzomyia trapidoi	22–24	2,280	20–30	51	20–22	2,123	18–28	47
*Lutzomyia panamensis**	24–26	8,474	20–30	41	22–24	11,233	16–26	54
*Lutzomyia pessoana**	22–24	247	20–30	49	20–22	300	16–26	59
Mansonia dyari	24–26	182,619	20–32	62	20–22	184,247	16–28	62
Haemagogus lucifer	24–26	660	20–32	33	22–24	957	16–28	48

* Measured at ground collection station.
** Maximum and minimum observed temperatures 38–17°C
Maximum and minimum observed dew point temperatures 30–15°C

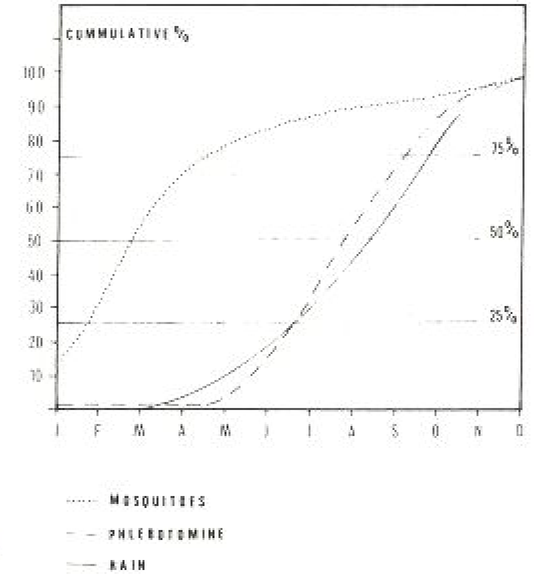

FIG. 1.—Cumulative (%) of rain, mosquito, and phlebotomine collections 1973–1977.

phlebotomine biting activity and the monthly amounts of rainfall. If the assumption is made that during the year you will be bitten by at least one mosquito and one phlebotomine, then during the period January through June, when about 25% of the annual rain has occurred there is an 80% probability of being bitten by a mosquito while from July through December there is an 80% probability of being bitten by a phlebotomine. A contingency table indicating the probability (%) of being bitten in any one month of the year and the % of the total annual rainfall for that month is shown in Table (2).

This table indicates the probability of being bitten in August, when about 12% of the annual rainfall occurs, is 20% for a phlebotomine, 18% for a *Culicoides*, and only 4% for a mosquito.

There are problems when all species of mosquitoes and phlebotomine are considered together, since one species may be dominant. In this study of more than 500,000 mosquitoes collected using man as live bait 87% were *Mansonia dyari*, while 50% of some 50,000 phlebotomines were *L. panamensis*; however, in this

Table 2.—Probability of being bitten in the month shown and rain as a % of annual rainfall.

Month	Phlebotomine % Year	Culicoides % Year	Mosquitoes % Year	Rain % Year
Jan	1.42	0.00	11.99	0.00
Feb	0.00	0.00	19.78	0.00
Mar	0.00	0.00	19.60	0.00
Apr	0.00	0.00	18.33	3.00
May	1.07	0.00	8.55	11.00
June	13.78	11.49	4.30	10.00
July	17.42	21.03	3.64	14.00
Aug	20.17	18.34	3.87	12.00
Sept	8.28	19.95	1.65	9.00
Oct	22.30	14.85	1.25	20.00
Nov	12.31	12.53	3.73	17.00
Dec	2.56	0.00	3.39	4.00

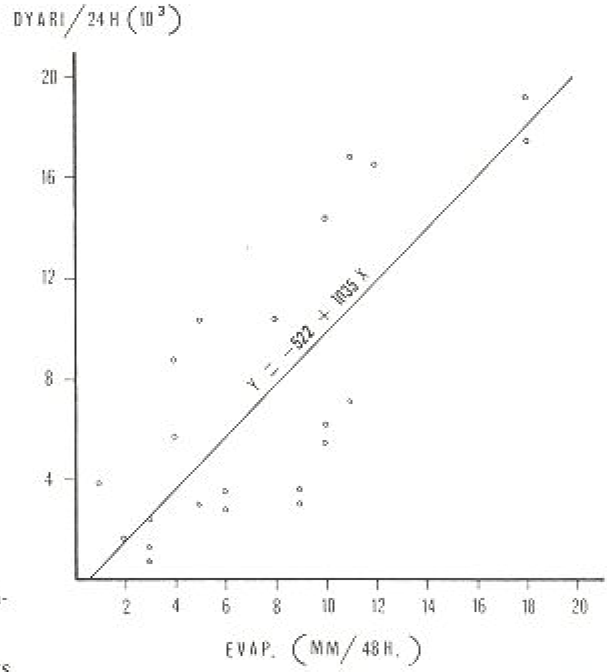

FIG. 2.—Linear relation between *Mansonia dyari* collections using man as live bait and the evaporation rate.

forested area the analysis is representative of the mosquito and phlebotomine biting preferences.

During the year 1977 the collections of *Mansonia dyari*, using man as live bait, were very high. The presence of *Pistia*, the water weed in which these mosquitoes breed near the island, produced ideal conditions for population explosions of this species. Our results indicate this mosquito bites more frequently in the dryer months of the year. It was of interest to determine how the evaporation rates were correlated with the biweekly collections of *Mansonia dyari*. The following empirical equation and the linear relation using the method of least squares shown in Figure (2) were determined using the rate of evaporation over the period of the day before and the day of the collection:

$$Y = -522 + 1035X$$

Where Y = number of *Mansonia dyari*/24 h and X = the Evaporation (mm)/48 h. The minimum value limiting the use of this equation is 0.5 mm/48 h of evaporation. That is to say, there must be at least 0.5 mm of evaporation during the 48 h. To test the goodness of fit of this linear regression line the correlation coefficient was computed as $r = 0.81$. This means that 66% of the variation in the collections is accounted for by the evaporation rate and is an example of the correlation with the other factor in the moisture budget. It indicates a measure of the biting activity of this mosquito, and it gives a relative estimate of the population size. An example of the use of this equation may help to explain its use. In June 1977 in the rainy season during one collection day, the evaporation rate was 3 mm/48 h, and the size of the collection was 1,235 mosquitoes. Using the equation, the best estimate for the number collected would be 2,583 mosquitoes. In March 1977 during one collection period there were 18 mm/48 h of evaporation and 19,129 mosquitoes collected. The equation gives an estimate of 18,108 mosquitoes collected. It has potential epidemiological applications in that it indicates the times of the year to expect large biting activity, and aids in the analysis of the structure of potential disease ecosystems. Furthermore, if there are negative results from the use of this equation, other biological or environmental factors are indicated as being more important at that time.

Conclusions

We have examined some of the possible correlations between the atmosphere and man biting activity of insect vectors. Within broad limits the distribution and activity of insects in an area is probably governed by the climate. It is sometimes difficult to separate variables of the climate and relate them to the organism under study, but some weather elements are so conspicuous that they may be isolated to show that one cause may produce one effect. We have tried to show this on the basis of probability: that is to say, biting activity is a maximum when the dew point or the air temperature fall into a certain range, or the probability of being bitten by one species is high or low given certain conditions of rainfall or evaporation.

Since the number of variables that may affect biting activity is complex and apt to be quite large it would seem that when using single atmospheric variables as predictors of potential biting activity it is particularly wise to accept answers in the terms of probabilities. We suggest on the basis of probability and given the presence of a host, that the potential for biting activity may be stimulation by certain atmospheric parameters.

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REFERENCES CITED

Chaniotis, B., J. Neeley, M. Correa, R. Tesh, and K. M. Johnson. 1971. Natural population dynamics of phlebotomine sandflies in Panama. J. Med. Entomol. 8: 339–52.

Galindo, P., H. Trapido, S. J. Carpenter, and F. S. Blandon. 1956. The abundance cycles of arboreal mosquitoes during six years at a sylvan yellow fever locality in Panama. Ann. Entomol. Soc. 49: 543–7.

Read, R. G., A. J. Adames, and P. Galindo. 1978. A model of microenvironment and man-biting tropical insects. Environ. Entomol. 7: 547–52.

Rutledge, L. C., and H. L. Mosser. 1972. Biology of immature sandflies (Diptera: Psychodidae) at the base of trees in Panama. Environ. Entomol. 1: 300–09.

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