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ENVIRONMENTAL ASPECTS CONCERNING THE ONSET OF THE FORAGING FLIGHT IN THE CAVE BAT *MYOTIS VELIFER*

by

Earl Gene McKinley

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GRADUATE COLLEGE

I hereby recommend that this dissertation prepared under my direction by Earl Gene McKinley entitled ENVIRONMENTAL ASPECTS CONCERNING THE ONSET OF THE FORAGING FLIGHT IN THE CAVE BAT MYOTIS VELIFER be accepted as fulfilling the dissertation requirement of the degree of Doctor of Philosophy

E. Lendell Cockrum
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6 July 1971
Date

After inspection of the final copy of the dissertation, the following members of the Final Examination Committee concur in its approval and recommend its acceptance:*

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SIGNED: Earl G McKinley

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ABSTRACT

During the summer of 1970 a relatively isolated maternity colony of *Myotis velifer* was observed during its daily foraging flight from Crystal Cave in Pinal County, Arizona. The gypsum cave, situated in the Lower Sonoran Life Zone at an elevation of 2300 feet, was continually stenothermal and stenohydric and neither its temperature nor relative humidity was found to affect the emergence of the population.

Several bats would examine the external environment for about 5 minutes immediately preceding the evening flight which would usually last 15 to 25 minutes. Most of the population (2500-3500) flew toward the west or east at a height of 5 to 15 feet above the ground and collisions with inanimate objects were observed on numerous occasions.

Variables measured and analyzed in this study were: visible light intensity; near-infrared light intensity; ambient temperature; ambient relative humidity; barometric pressure; wind velocity; and temperature and relative humidity within the cave. In addition, cloud cover and precipitation were noted.

The statistical implication is that the event of emergence is governed by a "multiple trigger". A level of light intensity probably acts as the primary cue while a rate of change in ambient temperature and a rate of change in atmospheric pressure appear to serve as secondary and tertiary cues respectively. The multiple trigger is also discussed from an evolutionary perspective.

INTRODUCTION

Most authors have associated the emergence of Microchiropterans from their diurnal roosts with either light intensity or time of sunset. Below are brief considerations of these parameters in addition to other phenomena which have been postulated to "trigger" the evening flight.

Sunset

In bats it seems unequivocal that a relationship exists between the time of sunset and the time of emergence, but the exact nature of this association has not in general been elucidated (Orr, 1954; Venables, 1943; Cutter, 1955; Vaughan, 1959; Greenhall, 1961; Phillips, 1966; Rice, 1957; Stebbings, 1968 and Herreid, II and Davis, 1966).

The evening departure of the flying squirrel, *Glaucomys volans*, from the den tree was shown to be closely correlated with sunset (De Coursey, 1960) and Schoennagel (1963) found that the evening feeding flight of mallard ducks ran parallel to the setting of the sun. Even *Drosophila* have an activity curve which is closely related to sunrise and sunset (Mitchell and Epling, 1951). Thus it is obvious that diverse organisms respond in a manner very predictable by the time of sunset.

Light Intensity

Although many authors agree that light intensity is intimately involved with the emergence of bats, they differ as to the nature of this relationship. For example: Church (1957) and Twente, Jr. (1956) are quite explicit in their opinion that light intensity governs departure while Krutzsch (1955) feels that light is part of the trigger. Herreid, II and Davis (1966) believe that unfavorable weather and possibly other factors may occasionally be implicated.

Although only time of sunset and time of emergence were considered, Church (1957) stated there was little doubt that intensity of light was the factor governing emergence. Based solely on graphic information, Prakash (1962) said the curves showed that the time of emergence of the pipistrelle was directly governed by the time of sunset and thereby according to the amount of twilight. Interestingly enough, one study involving _Myotis lucifugus_ concluded that time of emergence was highly correlated with certain intensities of illumination and that the threshold intensity at which bats flew appeared to increase from June through August (Miller, 1955). Such a correlation may imply that a particular level of light intensity initiated the evening flights. If this were true, one would expect no correlation at all since the intensity would be the same regardless of the time the bats emerged and the slope of the regression line would equal zero.

The literature abounds with references to the time of departure (emergence) and apparently it is assumed that a correlation between this time and another variate is meaningful. This is true only in the sense that a given variable may be used to predict the time of emergence or vice versa, but such a variate is not necessarily a trigger because the time of departure is not equivalent to the event of departure.

For example, time of emergence is a continuous non-random variable which must vary in only one direction, but the event of emergence is a discontinuous variate capable of only two states--emergence or non-emergence. Thus conclusions concerning a trigger for flight based in any way on the time of emergence should be questioned.

Temperature

The literature dealing with temperature and emergence is not conclusive, but it appears that temperature acts as a modifier of a more basic trigger.

Based on a comparison of ambient temperatures during June for two consecutive years, the opinion was that _Myotis velifer_ emerged later on relatively hot evenings (Vaughan, 1959). Support for this idea is found in the paper by Stebbings (1968) which indicates that pipistrelles emerge earlier during cold and cloudy weather. In contrast, ambient temperature was found to have no effect on the time of emergence in the pocketed free-tailed bat, _Tadarida femorosacca_ (Gould, 1961).

Not only is the time of emergence apparently influenced by ambient temperature, but relatively cold weather seems to reduce the number of bats which participate in the evening flight as pointed out by Venables (1943) and Church (1957). Similar results were obtained for _Drosophila pseudoobscura_ (Mitchell and Epling, 1951).

Since little or no temperature change was observed either inside or outside the cavern during the 15 minutes prior to emergence, Twente, Jr. (1955) concluded that temperature was not the trigger for departure in _Myotis velifer_. In a related study of _Tadarida mexicana_ the temperature within the cavern was determined to be unimportant as a trigger (Twente, Jr., 1956).

Relative Humidity

Information on relative humidity is indeed scant, however at least two workers (Provost and Kirkpatrick, 1952) believe that RH or saturation deficit may play an important role in the emergence of Lasiurus cinereus. Although mensuration involved ambient temperature, relatiave humidity and time of appearance, the data are inconclusive for lack of a sufficient number of observations.

Other

A paraphrased excerpt from Twente, Jr. (1955) states: departure is usually after sunset, but on two occasions the bats emerged before sunset and on both of these days it was either stormy or cloudy; light intensity however was within the range of non-cloudy days when departure was after sunset. Twente, Jr. goes on to suggest that hunger may explain the "early" departures. Perhaps hunger is a factor, but the early departures also easily fit into a light intensity hypothesis.

At least in one instance sound has been proposed as a potential stimulus for bats to take flight (Herreid, II and Davis, 1966). In one experiment Tadarida brasiliensis mexicana were prompted to leave their roost earlier than usual and as they flew past the experimental animal their squeaks apparently caused the subject to increase its oxygen consumption. After the Tadarida had flown by, the subject's metabolism returned to normal. These results suggest the possibility that bats, responding to some environmental parameter, may vocally or perhaps by their general activity induce other bats to take flight.

There are scattered indications that bats may respond in a peculiar manner to changes in the weather. In Trinidad, whenever Molossus ater and M. major foraged 1 to 2 hours earlier than usual, a storm with high wind and heavy rain invariably ensued (Greenhall, 1961). In a study of Pipistrellus mimus glaucillus, Prakash (1962) on three occasions observed these bats to suddenly disappear from the sky without reappearing. About one half hour later the area was hit with a destructive high speed storm. Such behavior may be mediated by a sudden change in atmospheric pressure.

Although the literature makes numerous references to time of sunset and light intensity, it contains little information about the related parameter of total solar radiation. Gould (1961) compared the time of emergence with the time of zero total solar radiation and reported that the evening departure of Tadarida femorosacca always occurred after total solar radiation reached zero. Total solar radiation during the day however did not appear to influence the time of emergence.

The trigger for the daily exodus of Tadarida mexicana from Carlsbad Caverns has been attributed to the slight interference of thermal air circulation (Allison, 1937). This "chimney draft" effect is supposedly common to all underground chambers which communicate directly with the atmosphere. The validity and generality of this concept remain uncertain.

Purpose of this Study

The vast majority of previous studies have contributed little toward isolation of the stimulus or stimuli responsible for the evening emergence of Chiroptera in general. The reason for this is two fold: (1) only a few variables were measured and (2) for the most part the conclusions reached were not supported with even a basic statistical analysis.

Primarily the intent of this investigation was to consider simultaneously most of the environmental parameters which may influence emergence and to determine statistically the relative importance of such stimuli. The following variables were thought to be of major importance: visible and near-infrared light intensities; ambient temperature; ambient relative humidity; atmospheric pressure; wind velocity; cave temperature and cave relative humidity. Cloud cover, precipitation and wind direction were believed to be of secondary significance.

DESCRIPTION OF STUDY SITE

The area investigated was Crystal Cave, known in past summers to house a maternity colony (70% females) of 4000 to 5000 Myotis velifer (Hayward, 1970). At an elevation of 2300 feet the small gypsum cave is located within the Lower Sonoran Life Zone (Lowe, 1964) approximately 8 miles south of Winkelman in Pinal County, Arizona at a north latitude of 32° 53.65' and a west longitude of 110° 41.28'.

In the immediate area of the cave the earth is sunken such that a "rim" circumscribes both the east-facing and west-facing entrances which are about 20 feet below the rim and the surrounding terrain. Bats were never seen flying from or roosting within the western portion of the cave, probably because of excessive light and the absence of standing water.

The eastern part of the cave however did contain standing water which maintained a high (95-100%) relative humidity and the consequent thermal stability was undoubtedly responsible for the narrow temperature range (usually 64-67°F) throughout the summer. Although the population did have access to a relatively warm and dry room, they were always found in the cooler and wetter chamber hanging about 5 feet above the water which suggests that water conservation in this Lower Sonoran form is related to microhabitat selection.

TYPICAL EVENING FLIGHT

It was quite common during late afternoon to observe bats flying within the eastern section of Crystal Cave. There did not however appear to be a pattern to such activity.

About 15 minutes prior to departure an increase in activity could be observed within the light zone of the cave and approximately 10 minutes later 1 or 2 bats would fly 5 to 10 feet outside the cave before returning. After a few seconds to perhaps a minute other bats would fly out even further before returning into the twilight zone of the cave. As the intensity of this behavior increased, more bats would fly increasingly further from the entrance until finally one or a few bats would initiate the evening flight. During this study there was not a single exception to this pre-flight behavior which Twente, Jr. (1955) termed "light sampling". An essentially identical behavioral sequence for *Myotis velifer* has also been described by Hayward (1970) and a very similar pattern has been noted for *Antrozous bunkeri* and *Corynorhinus rafinesquii* (Twente, Jr., 1955) in addition to *Tadarida mexicana* (Twente, Jr., 1956) and *Miniopterus schreibersii blepotis* (Dwyer, 1964).

With few exceptions, when the first bat left to forage it was immediately followed by the bulk of the population in one continuous flight at 5 to 15 feet above the ground. Most *M. velifer* departed in a westerly direction toward the San Pedro River about 2.0 miles distant although some bats flew toward the east. In contrast, very few individuals went north or south.

During 8 separate flights a bat was either heard or seen to strike the metal rod bearing the "wind sock" and once a bat was seen to collide with vegetation. On one occasion 2 individuals collided with one another just outside the entrance while "light sampling". *Myotis velifer* frequently collide with each other while flying within a cavern, but do not collide with the walls of the cavern (Twente, Jr., 1955) and Dr. E. L. Cockrum (personal communication) notes similar "careless" behavior in *Tadarida brasiliensis*.

The emergent flight from the cave would last 15 to 25 minutes and would end rather abruptly with only a few bats remaining in the cave. The time required for feeding was not investigated, but on one clear moonlight night bats began to return to the cave only 30 minutes after the first individual had left and within the next 10 minutes 80 *M. velifer* flew into the cave.

MATERIALS AND METHODS

Throughout the study during the summer of 1970 special care was taken not to disturb the maternity colony and there was no evidence of disturbance by other persons. For the most part, the cave was entered only to change the two Bendix hydrothermographs which were used primarily as "backups" for temperature and relative humidity measurements within the cave. All instrumentation, except the temperature and relative humidity sensors within the cave, was positioned about 20 feet directly above the eastern entrance. Creosotebush bordering the rim provided a blind which effectively concealed the instruments and the author from direct view of emerging bats, yet allowed observation of the area within the rim.

Evening measurements of environmental parameters were taken at 15 minute intervals beginning at 1 to 2 hours before local sunset and also at emergence when the first bat left the cave to forage. The local time (Mountain Standard Time) of emergence was noted and the time of sunset was later computed from Tables of Sunrise, Sunset and Twilight (Nautical Almanac Office, U. S. Naval Observatory, 1945). Sunset is defined as when the upper edge of the sun's disk is seen on an unobstructed horizon by an observer at zero elevation above the earth's surface in a level region.

Following is a brief description of the equipment and procedures used in this investigation.

Light Intensity

A silicon photovoltaic cell (International Rectifier, Model S4MU-4) having a linear output and a maximum sensitivity at 9000 Å was used in conjunction with a Kodak Wratten Filter to measure visible and near-infrared radiation. When the silicon cell was used without the filter the observed intensity was a summation of visible and near-infrared energy between approximately 4000 and 11000 angstroms. When the filter was placed over the cell, only wavelengths longer than 7200 Å reached the photocell. Thus near-infrared light intensity could be measured directly by utilizing the Wratten filter. Visible light intensity was obtained by subtracting the infrared reading from that obtained without the filter.

The photovoltaic cell and a resistance decade were connected in parallel to a d.c. meter (0-3 μa) which could be read to ±0.02 microamperes. Sensitivity of the system could be altered by factors of 10 by setting the decade to appropriate predeterminated values. The photocell was placed in the open about three feet above the ground and positioned to receive radiation primarily from the overhead sky (Venables, 1943).

Ambient Temperature

A mercury bulb thermometer (Taylor Instrument Co., Rochester, N. Y.) placed in open shade was used to obtain ambient temperature information. Reading accuracy of the instrument was ± $1^{\circ}F$.

Ambient Relative Humidity

Relative humidity was measured in open shade by a temperature compensated instrument (Honeywell) utilizing a lithium chloride sensor (± 1% RH). Accuracy of reading was ± 1% RH.

Barometric Pressure

Atmospheric pressure data were gathered by a barometer (Wallace and Tiernan Products, Inc., Belleville, N. J.; Model ML-102-G) having a scale error due to temperature less than the reading error of ± 0.1 millibar and consequently the scale error was ignored. The instrument was situated in open shade.

Cave Relative Humidity

Relative humidity within the cave was sensed by an electric hygrometric circuit element (Phys-Chemical Research Corp.; Model PCRC-55; ± 3% RH) which changed impedance as a function of RH. The sensor impedance was determined (remotely) by a portable wheatstone bridge (General Radio; Model 1650-A; ± 1%) and then compared to a standard calibration curve to obtain relative humidity which was later corrected for temperature.

The sensor was positioned two and one half feet above the soil-water interface and approximately 50 to 60 feet from the mouth of the cave. The wheatstone bridge was situated in open shade just above the entrance and its reading error was far less than the reading error (± 1% RH) of the calibration curve.

Cave Temperature

Temperature of the cave was sensed by a copper-constantan thermocouple, the output of which was determined by a potentiometer (Leeds-Northrup; Catalogue #8693; ± 0.2 of 1%) located just above the mouth of the cave. Temperature ($^{\circ}$F) was calculated using the thermocouple output (millivolts), the reference junction temperature and standard tables for copper-constantan thermocouples.

The thermocouple was located two and one half feet above the soil-water interface and about 50 to 60 feet from the entrance of the cave. The potentiometer was placed in open shade just above the entrance and the reading error was determined to be ± 0.01 millivolt.

Wind Velocity and Heading

A hand anemometer (Florite; Style 1000B) with a reading error of ± 20 feet/minute was held approximately 8 feet above the ground to measure wind velocity. Long thin strips of flagging tape were secured to the top of an 8 foot metal rod and served as a "wind sock".

The heading (degrees magnetic) of the wind was determined by a small hand compass with a reading error of ± 5 degrees.

Three readings each were obtained for wind velocity and wind heading and only the mean values were recorded.

Cloud Cover and Precipitation

Although cloud cover, precipitation and moonlight were not quantified in the usual sense, an attempt was made to accurately record such data as they developed and especially to note these variates during the evening flight. In addition, the general nature of the daily exodus was casually investigated with reference to the direction, altitude and duration of the flight.

RESULTS

Assumptions

From the beginning a major assumption was that Myotis velifer sensed either a level or rate of change in some environmental parameter or parameters. A related assumption was that the cue or cues changed significantly within some critical time period just prior to the evening flight.

The 7 minute interval immediately preceding emergence was thought to be approximately the "critical" period for two reasons: (1) the predicted time of departure was within ± 6.8 minutes of the actual time of emergence with 95% probability (Fig. 3, p. 27). The Standard Error of Estimate ($S_{y.x}$ = ± 3.4 minutes) is analogous to the Standard Deviation in that 2 $S_{y.x}$ (± 6.8 minutes) should contain about 95% of the data if the sample has a normal distribution (Spiegel, 1961). Although 95% confidence intervals are not indicated in Figure 3 (p. 27), it is apparent that the regression line, ± 6.8 minutes, does indeed enclose about 95% of the sample; (2) environmental "sensing" just outside Crystal Cave consistently lasted for about 4 to 8 minutes. Logically it seems that such an interval would allow the population to detect a significant change in some parameter with a minimal expenditure of energy.

Statistical Approach

For convenience the following abbreviations are utilized: 7 minutes *prior* to emergence = P; the *change* from 7 minutes prior to emergence to emergence = C; and *emergence* = E. Statistics are summarized in Appendix I.

If *M. velifer* respond to a particular level one would expect the mean of P to be significantly different from the mean of E and the variance of E should be significantly less than the variance of P and C. If however the bats respond to a rate of change one would again expect the mean of P to be significantly different from the mean of E, but the variance of C should be significantly less than the variance of P and E.

Tables and Figures

Pertinent raw data for all measured parameters are in Appendices A-H and basic statistical information for all major variables is seen in Table 1.

The variances in Table 1 are shown graphically, for comparison, in Figure 1 which also includes appropriate coefficients of variation. A negative sign preceding a coefficient does not alter the utility of the coefficient

Table 1. Basic statistical data for all major variables.

Visible light intensity (VL) and infrared light intensity (IL) were measured in the open just above the entrance to the cave. Ambient temperature (AT), ambient relative humidity (AH) and barometric pressure (BP) were measured in open shade just above the entrance to the cave. Wind velocity (WV) was measured just above the entrance to the cave at a height of approximately 8 feet above the surrounding terrain. Cave temperature (CT) and cave relative humidity (CH) were measured at the soil-water interface approximately 50 to 60 feet from the entrance. P is 7 minutes prior to emergence. C is the change from 7 minutes prior to emergence to emergence. E is emergence. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately. $\overline{X}$, S^2, S, N, t and p represent the arithmetic mean, variance, standard deviation, number of observations, Student's distribution and probability of significance (2-tailed test) respectively. Beneath the mean is the standard error of the mean.

Table 1. Basic statistical data for all major variables.

		$\bar{x}$	s^2	s	N	t	p
	P	3.07 ± .31	4.60	2.14	47		
VL	C	2.23 ± .27	3.41	1.85	47	8.305	<.001
	E	.84 ± .10	.49	.70	47		
	P	1.47 ± .15	1.04	1.02	47		
IL	C	1.09 ± .13	.82	.90	47	8.235	<.001
	E	.38 ± .05	.13	.35	47		
	P	86.63 ± 1.03	50.84	7.13	48	6.451	
AT	C	.73 ± .11	.62	.78	48		<.001
	E	85.90 ± 1.03	51.16	7.15	48		
	P	29.79 ± 3.21	495.12	22.25	48		
AH	C	-1.42 ± .53	13.41	3.66	48	-2.679	.01-.02
	E	31.21 ± 3.26	511.33	22.61	48		

Table 1, (Continued)

		$\bar{X}$	s^2	s	N	t	p
	P	932.06 ± .28	3.43	1.85	45		
BP	C	-.07 ± .01	.01	.10	45	-5.067	<.001
	E	932.13 ± .28	3.46	1.86	45		
	P	66.07 ± .17	1.34	1.16	45		
CT	C	.23 ± .14	.88	.94	45	1.586	.10-.20
	E	65.84 ± .20	1.73	1.31	45		
	P	99.89 ± .43	8.01	2.83	44		
CH	C	-.02 ± .12	.66	.81	44	-0.189	.80-.90
	E	99.91 ± .43	8.08	2.84	44		
WV	E	103.0 ±21.19	22441	149.80	50		

Figure 1. Variances and coefficients of variation for most major variables.

Lengths of the horizontal bars correspond to the numerical equivalents of variance to the immediate right. Bars may be compared only within a given variable since the scales are not identical for all variables. Numbers in parentheses refer to coefficients of variation corresponding to P or C or E and particular variables. Visible light intensity (VL) and infrared light intensity (IL) were measured in the open just above the entrance to the cave. Ambient temperature (AT), ambient relative humidity (AH) and barometric pressure (BP) were measured in open shade just above the entrance to the cave. Cave temperature (CT) and cave relative humidity (CH) were measured at the soil-water interface approximately 50 to 60 feet from the entrance. P is 7 minutes prior to emergence. C is the change from 7 minutes prior to emergence to emergence. E is emergence. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

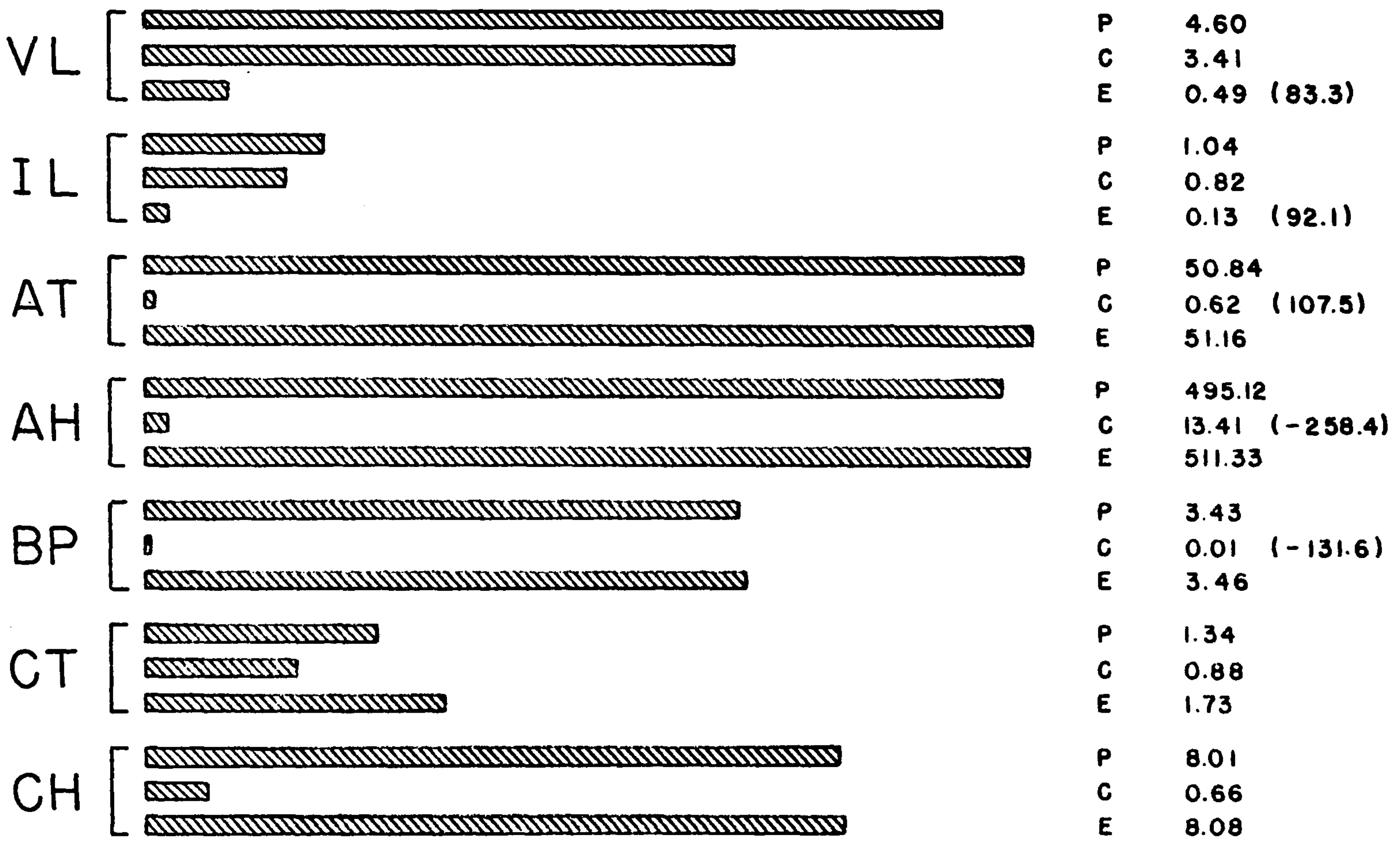

Figure 1. Variances and coefficients of variation for most major variables.

itself; it merely signifies that the corresponding mean difference ($\bar{d}$) is negative.

It is not always evident from an illustration whether two entities are really different. The purpose then of Table 2 is to establish which ratios of variance are statistically different from unity.

Figure 2 is designed to show the degree of overlap between 95% confidence intervals corresponding to the coefficients of variation in Figure 1 and is the primary basis for the conclusions from this investigation.

The matrix of Table 3 contains all possible linear correlation coefficients between the major variables as well as time of sunset and time of emergence. Recall that an ordinary (total) correlation coefficient (r) indicates the degree of association between two variables, but it reveals nothing about the nature of the relationship. The actual correlation between two co-variates is realized only when all other variables affecting either of the co-variates are simultaneously held constant. A true correlation may have its value falsified by the existence of another distinct correlation not excluded from the data and tending to either increase or decrease the correlation that is sought (Simpson, Roe and Lewontin, 1960). As an example, Table 3 shows a positive correlation (r = 0.68) between time of emergence and cave relative humidity

Table 2. Variance ratios and corresponding levels of significance for most major variables.

Visible light intensity (VL) and infrared light intensity (IL) were measured in the open just above the entrance to the cave. Ambient temperature (AT), ambient relative humidity (AH) and barometric pressure (BP) were measured in open shade just above the entrance to the cave. Cave temperature (CT) and cave relative humidity (CH) were measured at the soil-water interface approximately 50 to 60 feet from the entrance. P is the variance 7 minutes prior to emergence. C is the variance of the change from 7 minutes prior to emergence to emergence. E is the variance at emergence. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately. F is the ratio of two variances (e.g., P and C) for a given variable (e.g., AT). p is the probability of significance (2-tailed test).

Table 2, Variance ratios and corresponding levels of significance for most major variables.*

	P-C	P-E	C-E
VL	F = 1.351	F = 9.388	F = 6.951
	p >.10	p <.005	p <.005
IL	F = 1.275	F = 8.000	F = 6.277
	p >.10	p <.005	p <.005
AT	F = 82.667	F = 1.006	F = 83.187
	p <.005	p >.10	p <.005
AH	F = 36.924	F = 1.033	F = 38.133
	p <.005	p >.10	p <.005
CT	F = 1.516	F = 1.291	F = 1.957
	p <.10	p >.10	p <.025
CH	F = 12.173	F = 1.009	F = 12.280
	p <.005	p >.10	p <.005
BP	F = 343.000	F = 1.009	F = 346.000
	p <.005	p >.10	p <.005

Figure 2. Coefficients of variation and corresponding 95% confidence intervals for potential triggers.

Horizontal lines extending from the vertical bars represent coefficients of variation and the lengths of the bars represent the corresponding 95% confidence intervals. Visible light intensity (VL) and infrared light intensity (IL) were measured in the open just above the entrance to the cave. Ambient temperature (AT), barometric pressure (BP) and ambient relative humidity (AH) were measured in open shade just above the entrance to the cave.

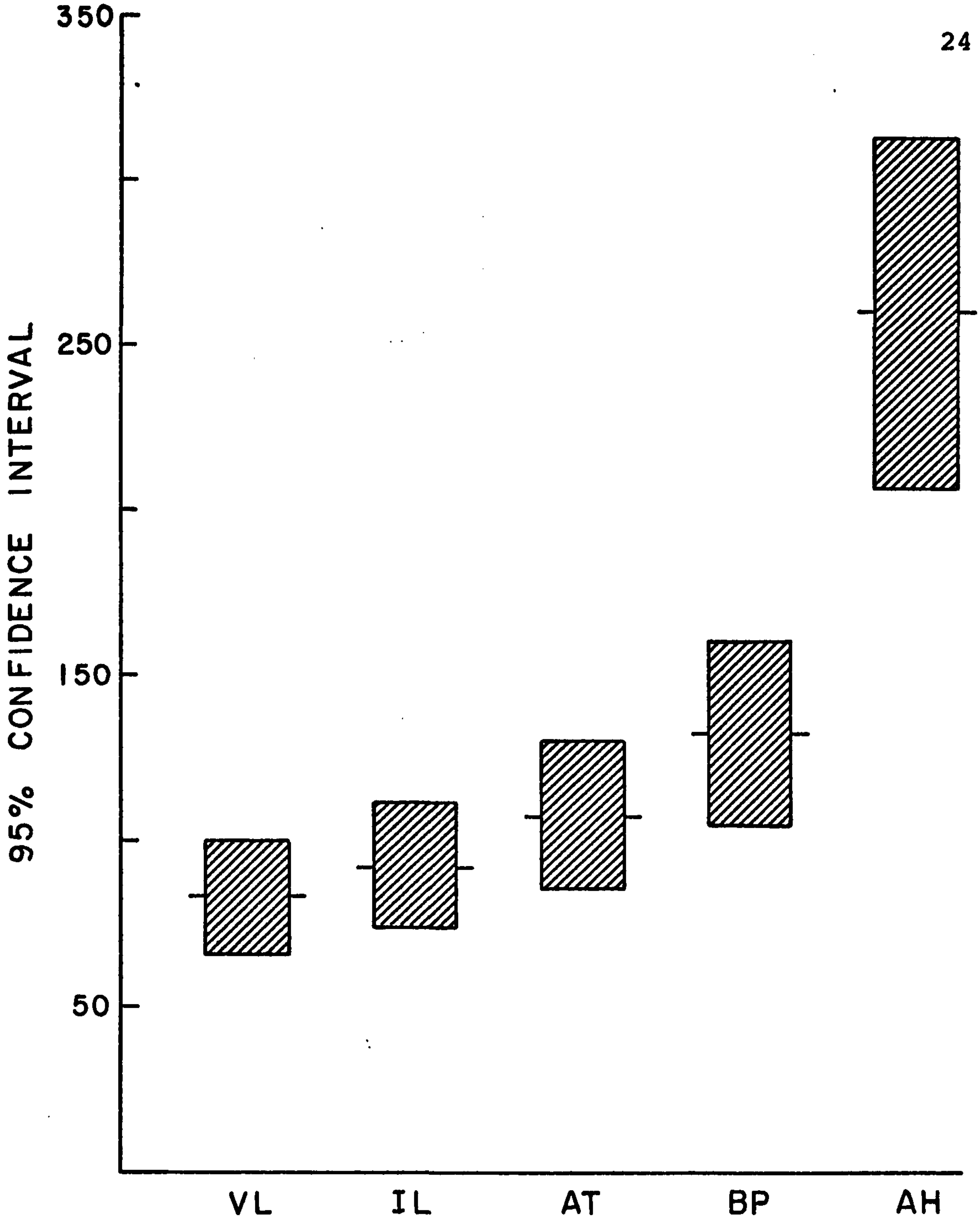

Figure 2. Coefficients of variation and corresponding 95% confidence intervals for potential triggers.

Table 3. Linear correlation matrix between all major variables in addition to time of sunset and time of emergence.

Emergence time (ET) in the evening was the time (MST) that the first bat left the cave and did not return immediately. Sunset time (ST) was the time (MST) computed from tables of sunrise, sunset and twilight and was defined as the time when the upper edge of the sun's disk was seen on an unobstructed horizon by an observer at zero elevation above the earth's surface in a level region (Nautical Almanac Office, U. S. Naval Observatory, 1945). Actual time of sunset was somewhat earlier than the computed time of sunset due to mountains west of the cave. Visible light intensity (VL) and infrared light intensity (IL) were measured in the open just above the entrance to the cave. Ambient temperature (AT), ambient relative humidity (AH) and barometric pressure (BP) were measured in open shade just above the entrance to the cave. Wind velocity (WV) was measured just above the entrance to the cave at a height of approximately 8 feet above the surrounding terrain. Cave temperature (CT) and cave relative humidity (CH) were measured at the soil-water interface approximately 50 to 60 feet from the entrance. Upper numbers are correlation coefficients and lower numbers are probabilities (p) of significance.

Table 3. Linear correlation matrix between all major variables in addition to time of sunset and time of emergence.

	S T	V L	I L	A T	A H	B P	W V	C T	C H
E T	.98 $p < .001$	−.58 $p < .001$	−.57 $p < .001$	.54 $p < .001$	.09 $p > .10$	−.09 $p > .10$	.21 $p > .10$	−.14 $p > .10$	.68 $p < .001$
S T		−.49 $p < .01$	−.49 $p < .01$	.47 $p < .01$	.20 $p > .10$	−.03 $p > .10$	.21 $p > .10$	−.09 $p > .10$	.76 $p < .001$
V L			.93 $p < .001$	−.40 $p < .02$	.18 $p > .10$	−.09 $p > .10$	−.18 $p > .10$	−.01 $p > .10$	−.11 $p > .10$
I L				−.37 $p < .05$	.14 $p > .10$	.01 $p > .10$	−.14 $p > .10$	−.06 $p > .10$	−.12 $p > .10$
A T					−.54 $p < .001$	−.25 $p > .10$	.36 $p < .05$	−.11 $p > .10$	.20 $p > .10$
A H						.23 $p > .10$	−.14 $p > .10$	.14 $p > .10$	.40 $p < .02$
B P							−.05 $p > .10$	.16 $p > .10$	.21 $p > .10$
W V								.00 $p > .10$	.15 $p > .10$
C T									−.03 $p > .10$

which is not apparent from Figure 3 and Figure 10 (p. 34). If a partial correlation is computed for these variates holding only time of sunset constant, the correlation changes from +0.68 to -0.50.

Because the coefficients in Table 3 represent ordinary rather than partial correlations and since the event of emergence cannot co-vary with other parameters, it is unequivocal that the matrix does little to fulfill the purpose of this investigation. The matrix is included then to exemplify why "correlations" must be critically examined and interpreted with common sense.

Each figure listed below demonstrates the day-to-day variability of a given parameter at 7 minutes prior to departure and also at emergence. The figures in themselves however do not influence the conclusions which are based on Figure 1 (p. 21), Figure 2 (p. 24), Table 1 (p. 19) and Table 2 (p. 23).

Time of Sunset	Fig. 3, p. 27
Time of Emergence	Fig. 3, p. 27
Visible Light Intensity	Fig. 4, p. 28
Infrared Light Intensity	Fig. 5, p. 29
Ambient Temperature	Fig. 6, p. 30
Barometric Pressure	Fig. 7, p. 31
Ambient Relative Humidity	Fig. 8, p. 32
Cave Temperature	Fig. 9, p. 33
Cave Relative Humidity	Fig. 10, p. 34
Wind Velocity	Fig. 11, p. 35
Wind Heading	Fig. 12, p. 36

Figure 3. Time of sunset and emergence.

Time of sunset at the cave was computed from tables of sunrise, sunset and twilight and was defined as the time when the upper edge of the sun's disk was seen on an unobstructed horizon by an observer at zero elevation above the earth's surface in a level region. (Nautical Almanac Office, U. S. Naval Observatory, 1945) Actual time of sunset was somewhat earlier than the computed time of sunset due to mountains west of the cave. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately. A linear correlation (r = -.98) between the time of emergence and the date was significant at the .001 level.

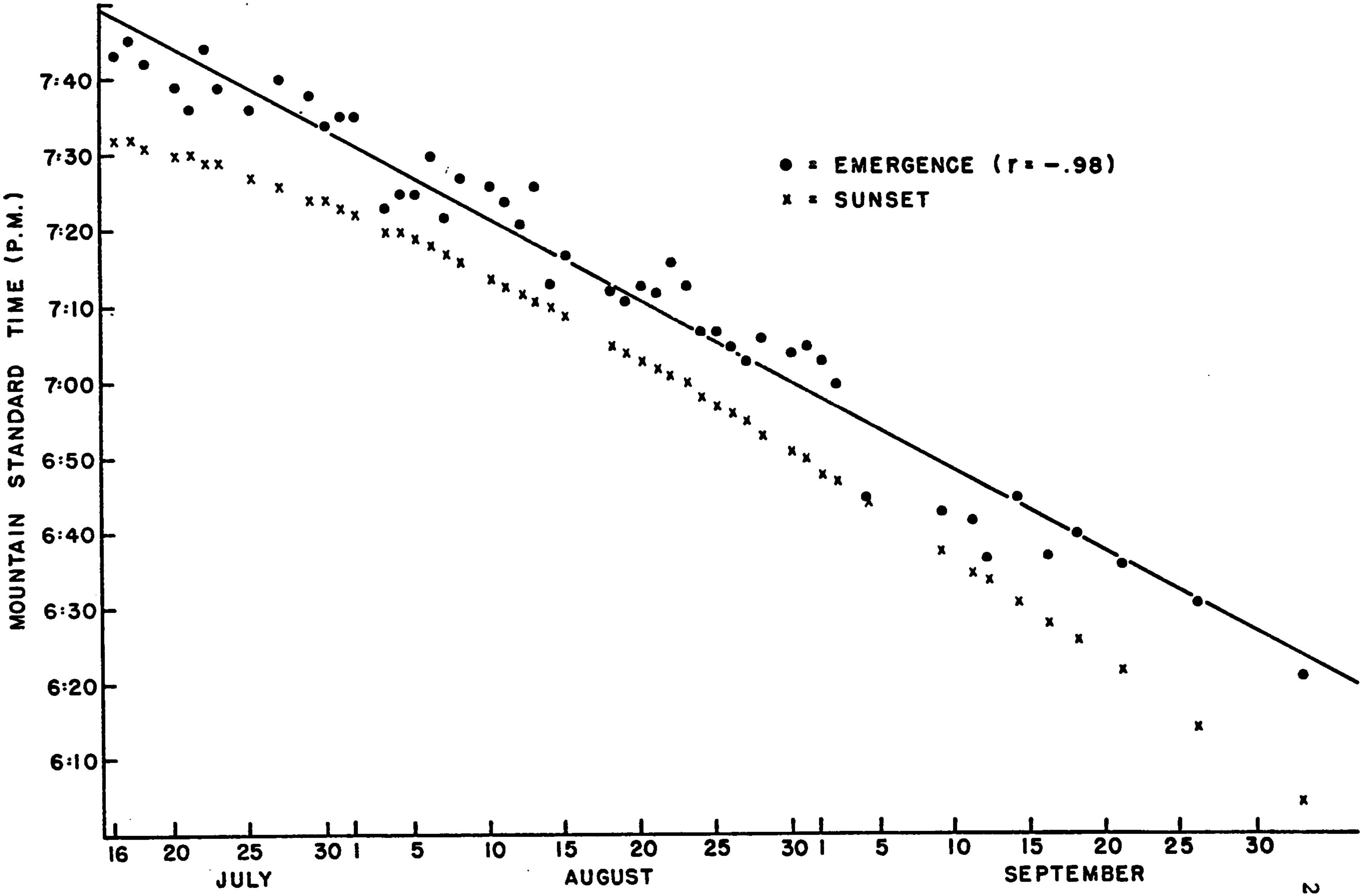

Figure 3. Time of sunset and emergence.

Figure 4. Visible light intensity.

Visible light intensity was measured in the open just above the entrance to the cave. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

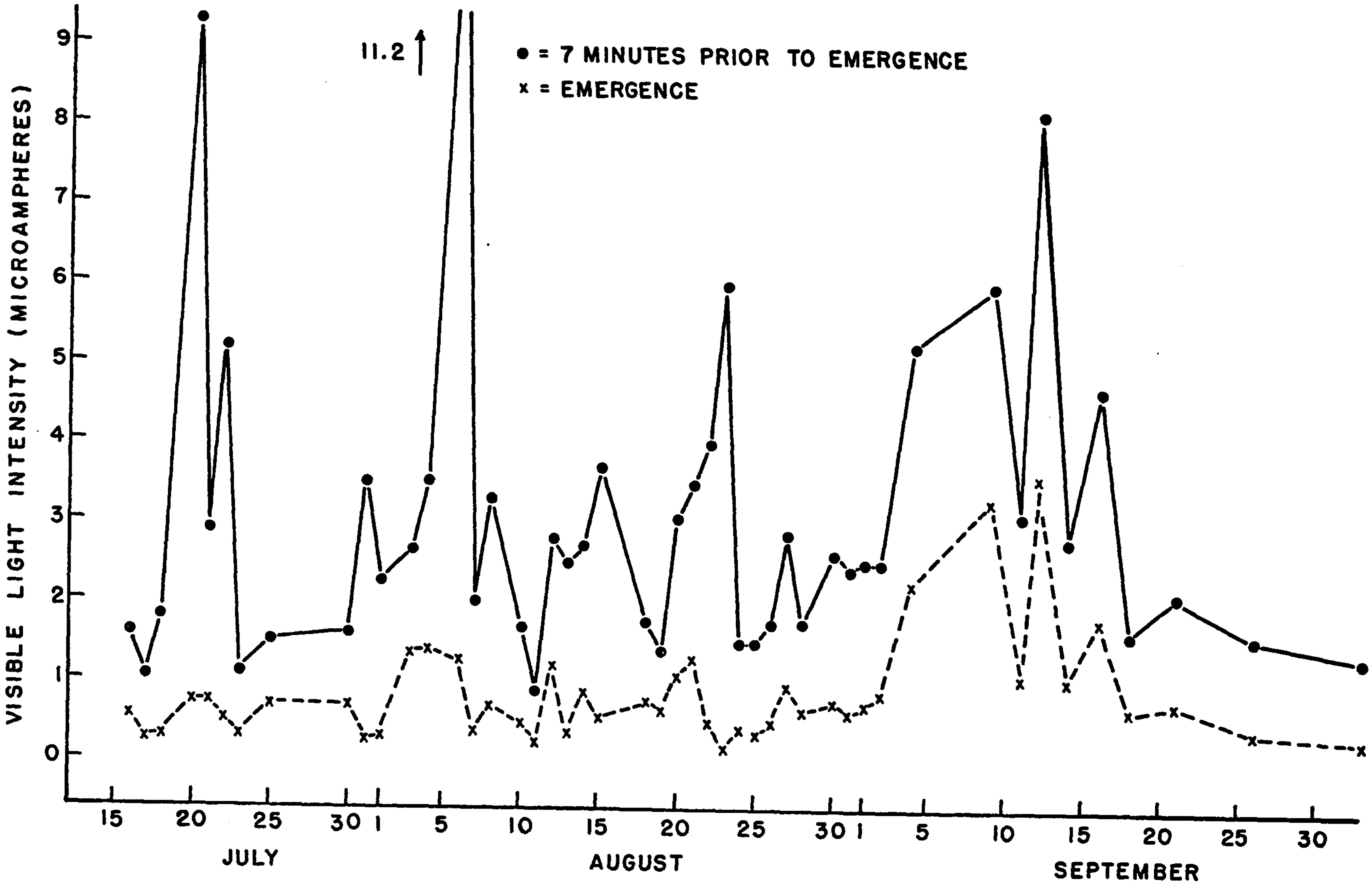

Figure 4. Visible light intensity.

Figure 5. Infrared light intensity.

Infrared light intensity was measured in the open just above the entrance to the cave. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

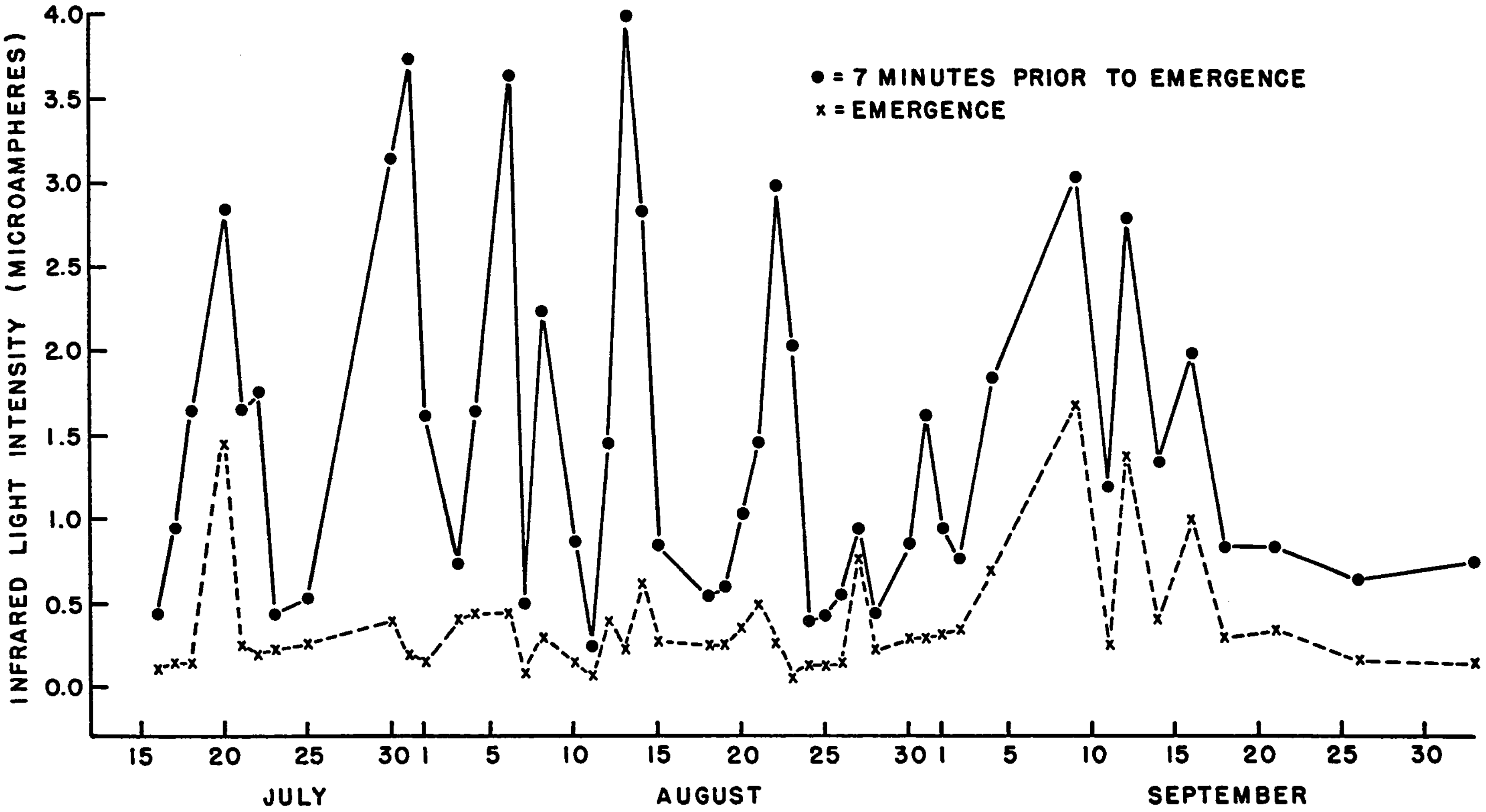

Figure 5. Infrared light intensity.

Figure 6. Ambient temperature.

Ambient temperature was measured in open shade just above the entrance to the cave. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

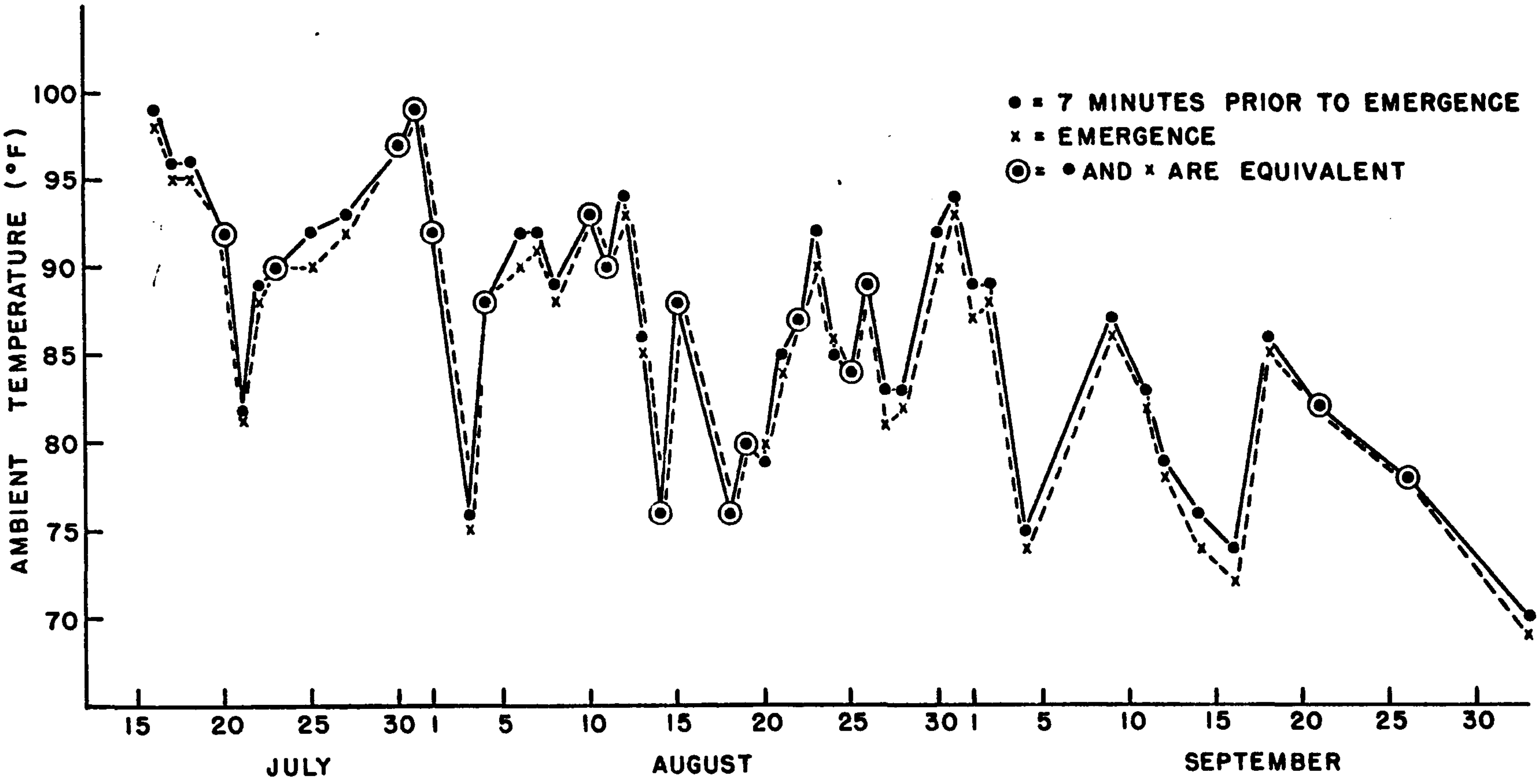

Figure 6. Ambient temperature.

Figure 7. Barometric pressure.

Barometric pressure was measured in open shade just above the entrance to the cave. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

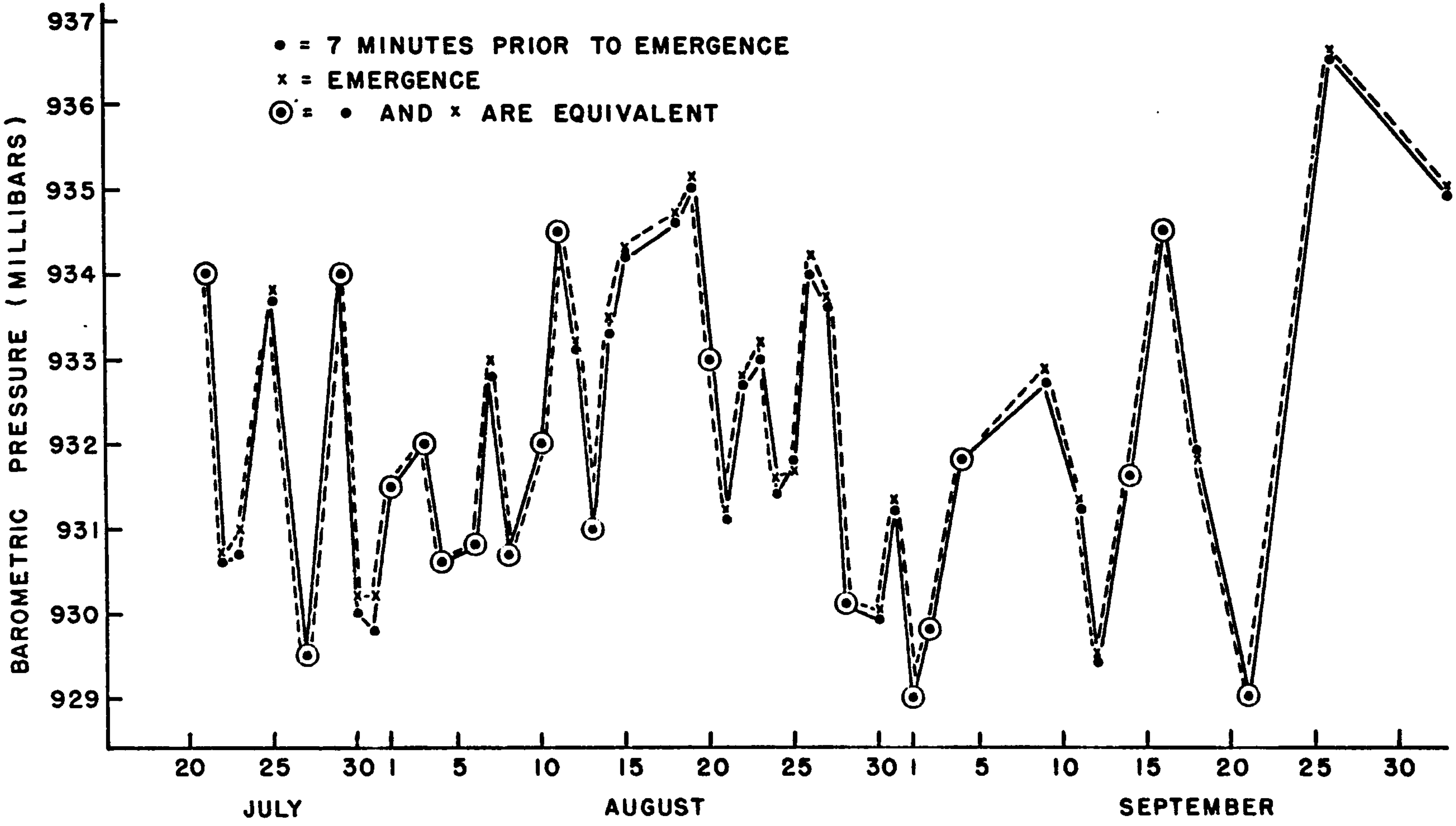

Figure 7. Barometric pressure.

Figure 8. Ambient relative humidity.

Ambient relative humidity was measured in open shade just above the entrance to the cave. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

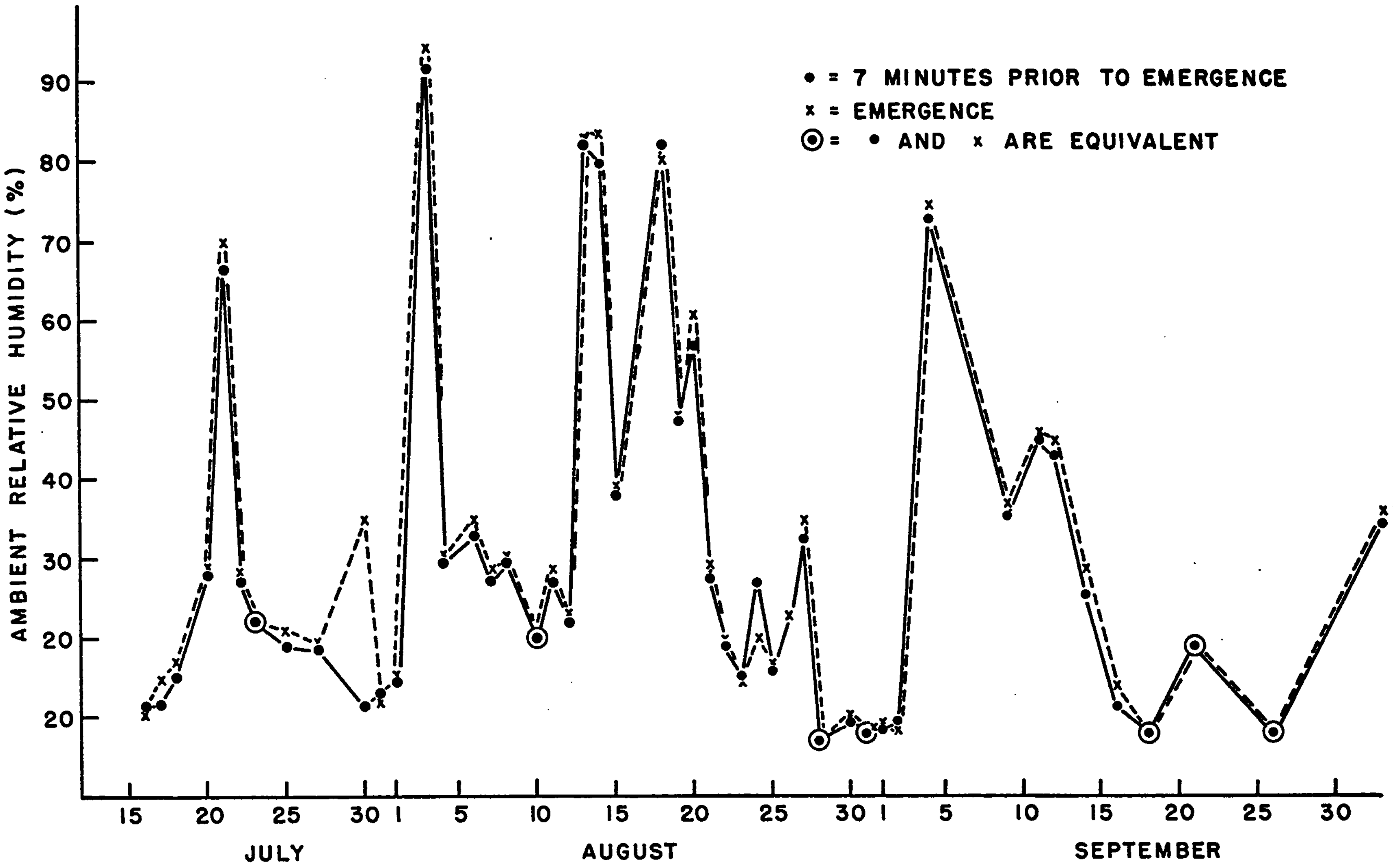

Figure 8. Ambient relative humidity.

Figure 9. Cave temperature.

Temperature within the cave was measured (remotely) at the soil-water interface approximately 50 to 60 feet from the entrance. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

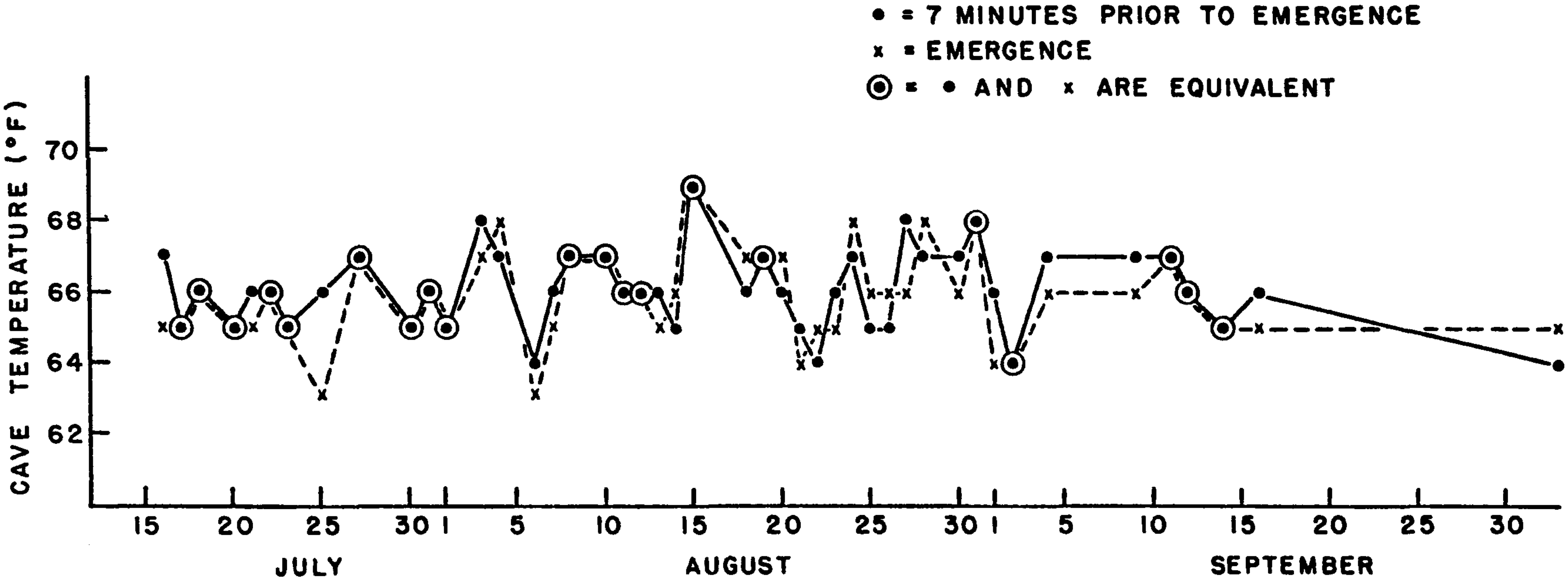

Figure 9. Cave temperature.

Figure 10. Cave relative humidity.

Relative humidity within the cave was measured (remotely) at the soil-water interface approximately 50 to 60 feet from the entrance. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

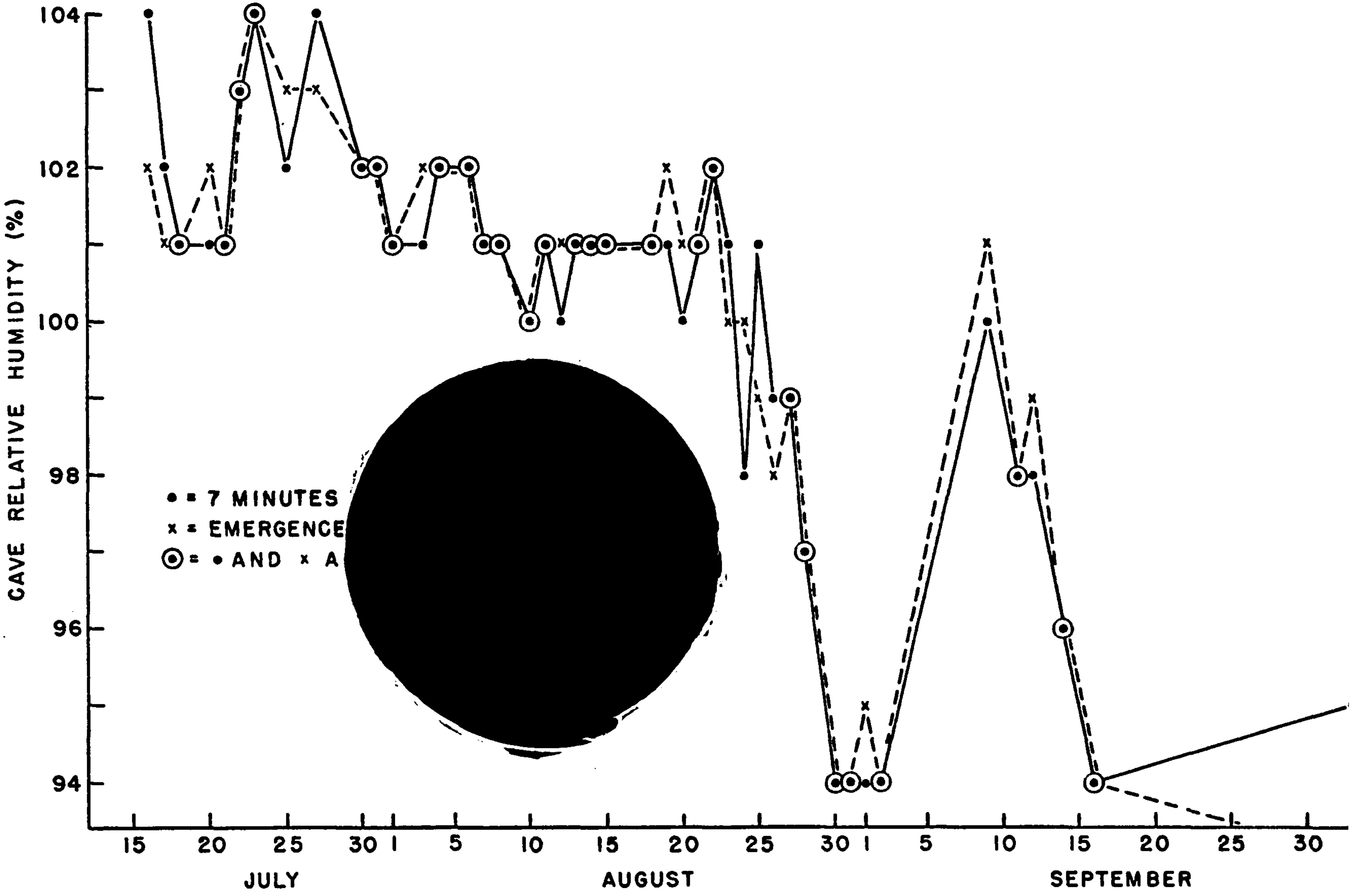

Figure 10. Cave relative humidity.

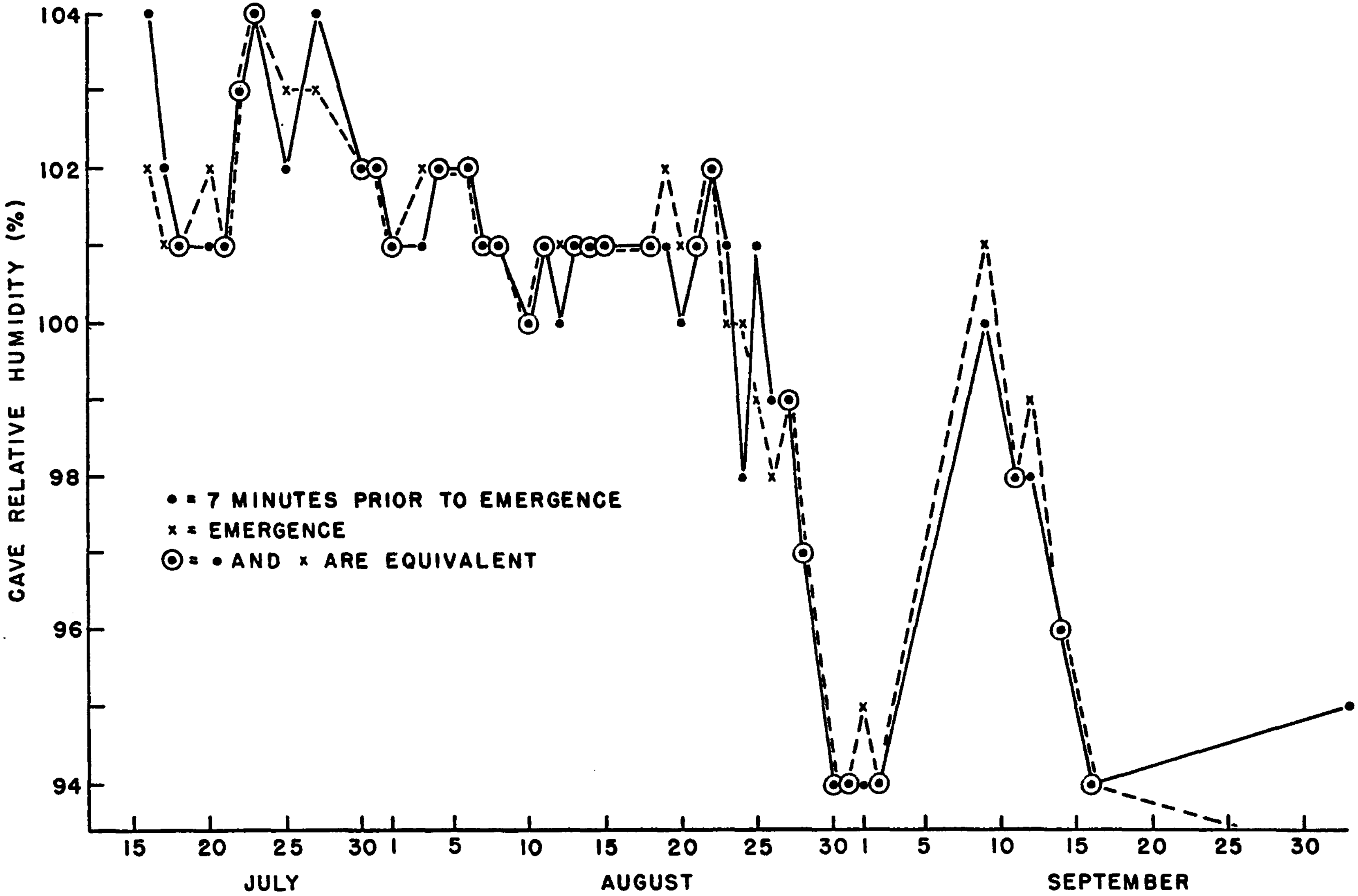

Figure 10. Cave relative humidity.

Figure 11. Wind velocity at emergence.

Wind velocity was measured just above the entrance to the cave at a height of approximately 8 feet above the surrounding terrain. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately. Wind velocity is plotted against the date and frequency of occurrence.

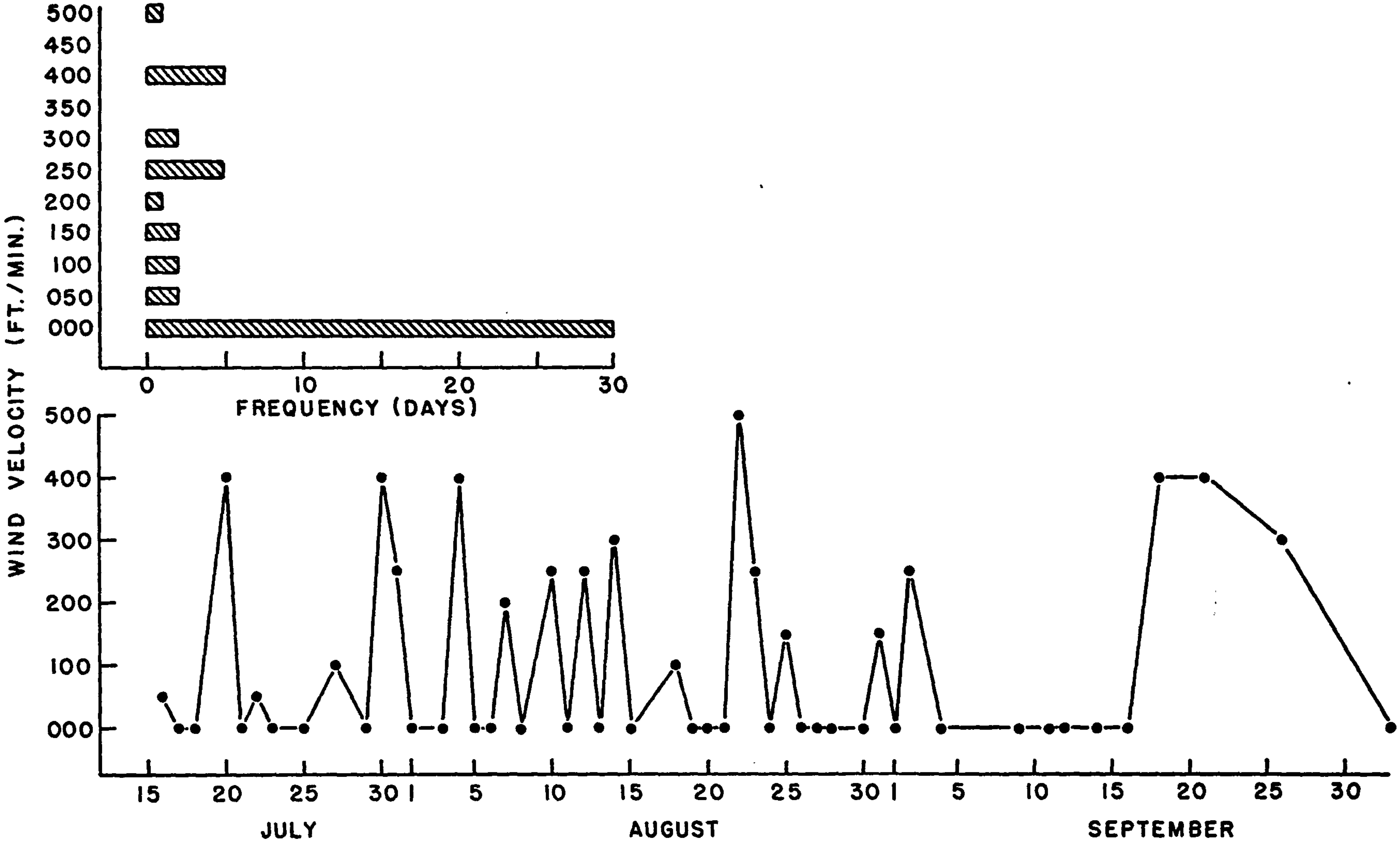

Figure 11. Wind velocity at emergence.

Figure 12. Magnetic compass heading of wind at emergence.

Solid arrows indicate observed headings of wind while dashed arrows indicate the heading which would blow directly into the cave. The length of a solid arrow represents relative frequency. Emergence in the evening was defined as the event of the first bat leaving the cave and not returning immediately.

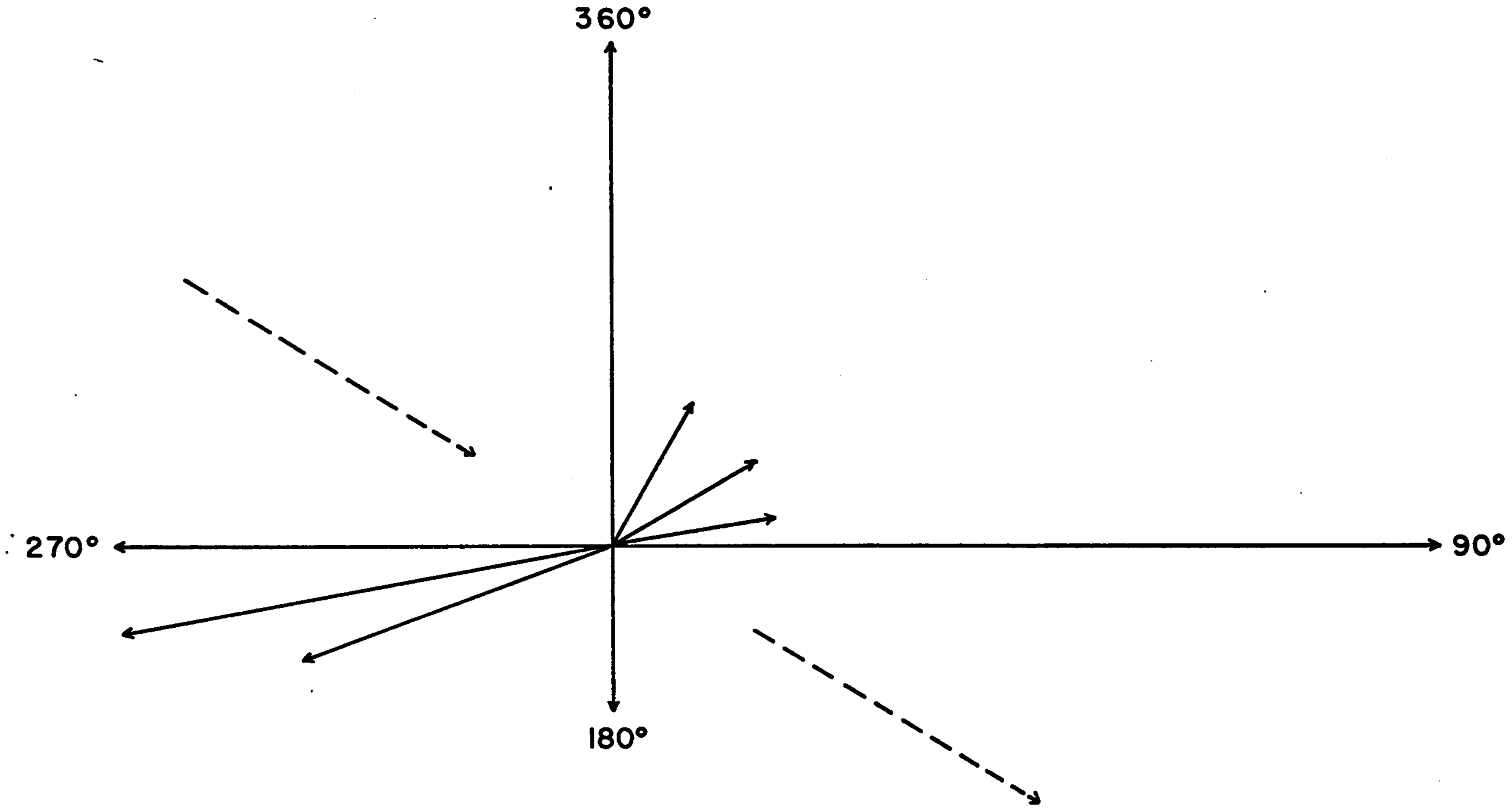

Figure 12. Magnetic compass heading of wind at emergence.

DISCUSSION

Unimportant Variates

It is improbable that cave temperature has any influence on emergent behavior for two reasons: (1) the mean values of P and E are statistically identical (Table 1, p. 19) and (2) the variance of E is not significantly less than the variance of P and C nor is the variance of C significantly less than the variance of P and E (Fig. 1, p. 21 and Table 2, p. 23). A similar conclusion was reached for *Myotis velifer* (Twente, Jr., 1955) and *Tadarida mexicana* (Twente, Jr., 1956).

Although Figure 1 (p. 21) and Table 2 (p. 23) indicate that a rate of change in RH of the cave may act as a trigger this possibility is ruled out by the very high probability that P and E are equal (Table 1, p. 19).

The likelihood that a threshold of wind velocity mediates the evening flight is remote although interference in thermal air circulation has been postulated as the trigger for *Tadarida mexicana mexicana* which roost in underground chambers (Allison, 1937). At Crystal Cave the wind velocity at emergence was highly variable (Table 1, p. 19) and on most days it was immeasurable (Fig. 11, p. 35). This plus the fact that the entrance is 20 feet beneath the surrounding terrain argues against the importance of this variable.

Wind as it affects emergence has not been rigidly investigated although Constantine (1967) reported that the Mexican Free-Tailed Bat would leave in a strong wind and be carried in the opposite direction which essentially agrees with observations at Crystal Cave. When *M. velifer* emerged into a strong wind they would be tossed about and carried to heights of 50 to 60 feet, but the wind was never observed to delay or halt departure in contrast to observations by Stebbings (1968) and Church (1957).

From the relation between time of sunset and time of emergence it may appear that *M. velifer* have an endogenous "clock" that in itself mediates departure. This idea however does not coincide with the behavior of *Myotis myotis* as reported by DeCoursey and DeCoursey (1964) who discovered that artificial illumination of the flight path at the normal time of exit resulted in intense "sampling", but prevented the departure of most individuals; when the lights were turned off, most of the bats left immediately. If an endogenous clock is geared to the time of sunset one would expect departure, relative to sunset, to be constant throughout the year. However as indicated by Figure 3 (p. 27) departure seems to be relatively later during late summer and early fall which agrees with the findings of

Venables (1943), Prakash (1962) and Phillips (1966) for *Pipistrellus pipistrellus*, *Pipistrellus mimus* and *Eptesicus fuscus* respectively. Thus it is doubtful that the time of sunset is important to the emergent behavior of *Myotis velifer* regardless of the high correlation (r = .98) seen in Table 3 (p. 25).

Possible Cues

There are five variables which satisfy the criteria already established for potential triggers and Figure 1 (p. 21) clearly emphasizes that visible and infrared light intensities comprise one group and that ambient temperature, barometric pressure and ambient relative humidity constitute the other assemblage.

A level of visible light intensity easily qualifies as a potential cue because the variance of E is significantly less than the variance of P and C (Fig. 1, p. 21 and Table 2, p. 23) and because the mean of P is significantly different from the mean of E (Table 1, p. 19). A level of infrared light intensity also qualifies for the same reasons.

A rate of change in ambient temperature is also a potential trigger for departure since the variances of P and E are statistically equivalent, but each significantly different from the variance of C (Fig. 1, p. 21 and Table

2, p. 23) and because the mean of P is significantly different from the mean of E (Table 1, p. 19). The same can be said for a rate of change in barometric pressure and ambient relative humidity.

Multiple Trigger

Coefficients of variation and corresponding 95% confidence intervals (Simpson, Roe and Lewontin, 1960) were computed for the five potential triggers to allow a direct comparison of relative dispersion between any two of the five variates. On this basis it was concluded that a threshold of light intensity (especially visible) was the factor most responsible for initiating the evening flight at Crystal Cave. The same logic suggested that a rate of change in ambient temperature and a rate of change in atmospheric pressure were secondary and tertiary components of a "multiple trigger".

There is mostly inconclusive evidence from the literature to support the multi-trigger concept relative to light intensity. On two cloudy or stormy evenings _M. velifer_ were observed to emerge relatively early although the visible light intensity was within the range observed on clear days when the population emerged relatively late (Twente, Jr., 1955). Earlier departure on cloudy days has also been noted for con-generic _Myotis myotis_ (DeCoursey and DeCoursey, 1964), Tadarida (Twente, Jr., 1956; Krutzsch, 1955; and Herreid, II and Davis, 1966) and Pipistrellus (Stebbings, 1968 and Prakash, 1962). Such observations however must be held suspect because clouds may actually increase light intensity depending on the position of the cloud cover with respect to the sun and light sensor (Author, unpublished). The fact however that artificial illumination did, until extinguished, prevent the departure of Myotis myotis (DeCoursey and DeCoursey, 1964) strongly implicates light intensity as the trigger for emergence.

Table 1 (p. 19) suggests another reason why light intensity may be the key environmental variable. Because the N numbers for all major variates are virtually identical, the t statistic is a good measure of how fast the mean value of a variable changes per unit time. If one may assume that a fast change is easier to detect than a slow one, then light intensity becomes a relatively good candidate for the primary trigger.

Although Figure 2 (p. 24) implies that infrared light intensity is an important aspect of the multiple trigger, this implication is probably an environmental artifact. Since M. velifer cannot apparently see red light (Twente, Jr., 1955) due to a cone free retina (Walls, 1942), it seems doubtful that they can detect near-infrared radiation. On one occasion the present investigator exposed two caged M. velifer to an infrared source without any overt response. In addition, many nocturnal rodents appear oblivious to red light (Finley, Jr., 1959).

The indication that a rate of change in ambient temperature secondarily influences emergent behavior is superficially strengthened by casual observations of ambient temperature (Church, 1957 and Stebbings, 1968). Little support is derived from studies which lack proper quantification (Twente, Jr., 1956; Gould, 1961; and Vaughan, 1959). Few if any workers even attempt to differentiate a rate of change in temperature from a level of temperature. Consequently the exact role of ambient temperature is still unclear.

On July 20, 1970 the population at Crystal Cave emerged very early relative to total and infrared light intensities. As M. velifer left the cave they flew by the author closer than usual apparently little aware of Homo sapiens. A severe storm of lightning, wind and rain followed in approximately one half hour. These events closely approximate those observed for Molossus ater and M. major (Greenhall, 1961) and Pipistrellus mimus (Prakash, 1962). There is also some evidence that raccoons respond behaviorally to pronounced pressure changes (Sharp and Sharp, 1956).

As pointed out by Brown (1960) atmospheric pressure is rhythmic with solar and lunar periods such that a reversal from a declining to an increasing pressure usually occurs at about 6 p.m. The timing of this reversal tends to overlay the seasonal shift in the time of sunset. These findings may be significant in view of the fact that the colony at Crystal Cave almost always emerged shortly after (1-2 hours) the evening reversal when the pressure was steady or climbing (Fig. 7, p. 31 and Appendix D). These facts concur with the conclusion by Brown (1960) that atmospheric pressure is correlated with a metabolic change in all animals and plants studied from algae to vertebrates. More interestingly, the metabolic change always occurs at times of pressure change (2-6 a.m. and about 6 p.m.).

From an evolutionary point of view, what is the selective advantage, if any, of a multiple trigger? Evaporative water loss may be substantial in relatively small animals with a high surface to volume ratio (Cloudsley-Thompson, 1960). High ambient temperature (Herreid,II and Schmidt-Nielsen, 1966) and low water vapor pressure (Procter and Studier, 1970) have been shown to greatly increase EWL in <u>Eptesicus fuscus</u> and pregnant

Myotis lucifugus. Since free water is scarce during the water-dependent gestation period of Myotis velifer in southern Arizona, evaporative cooling appears to be an "expensive" means of combating heat stress. The maternity colony could however circumvent the water problem by foraging in a low ambient temperature and a high relative humidity.

A high RH may however increase heat stress by retarding evaporative cooling. This conflict between water conservation and evaporative cooling suggests that Lower Sonoran bats (especially maternity colonies) may be especially tolerant to high ambient temperatures. Substantiation for this logic is given by Licht and Leitner (1967) who found the lethal body temperature to be 43.5°C for Myotis yumanensis, Tadarida brasiliensis and Antrozous pallidus. In addition, Tadarida brasiliensis lives longer than Myotis lucifugus at 27.0°C (Herreid, II, 1963). In terms of water conservation and thermal stress, natural selection should favor a mechanism which senses temperature and/or relative humidity and which recognizes the limiting range of each parameter. Since the two variables are inversely related, an accurate detection of either may suffice.

Foraging activity imposes an additional thermal problem by increasing metabolic heat production. Thus from an energetics point of view it is advantageous to limit feeding to times of insect abundance. Since ambient temperature, atmospheric pressure, cloud cover and phase of the moon all influence insect activity (Williams, 1940), the selective advantage of simultaneously sensing light, temperature and pressure is unmistakable. Also, it is logically disadvantageous to forage during a storm and thus a pressure sense may serve a dual function.

In summary, the theoretical advantage of a multiple trigger is to enhance the probability of emerging into a favorable range of photic, hydrothermal and barometric environments which coincide with nocturnal insect activity.

CONCLUSIONS

From a statistical perspective the conclusions from this study are: (1) emergence as an event is governed by a "multiple trigger" and (2) a level of light intensity probably acts as the major cue while a rate of change in ambient temperature and a rate of change in atmospheric pressure appear to serve as secondary and tertiary triggers respectively.

APPENDIX A

TIME OF SUNSET AND EMERGENCE (P.M.)

The date followed by an asterisk means that time of sunset and time of emergence were utilized in computing the correlation matrix found in the Results of this manuscript. MST represents Mountain Standard Time.

Date		Sunset (MST)	Emergence (MST)
July	16	732	743
	17	732	745
	18	731	742
	20	730	739
	21*	730	736
	22*	729	744
	23*	729	739
	25*	727	736
	27	726	740
	29	724	738
	30*	724	734
	31*	723	735
August	1*	722	735
	3*	720	723
	4*	720	725
	5	719	725
	6*	718	730
	7*	717	722
	8*	716	727
	10*	714	726
	11*	713	724
	12*	712	721
	13*	711	726
	14*	710	713
	15*	709	717
	18*	705	712
	19*	704	711
	20*	703	713
	21*	702	712
	22*	701	716
	23*	700	713
	24*	658	707
	25*	657	707
	26*	656	705
	27*	655	703
	28*	653	706
	30*	651	704
	31*	650	705

Date		Sunset (MST)	Emergence (MST)
September	1*	648	703
	2*	647	700
	4	644	645
	9*	638	643
	11*	635	642
	12*	634	637
	14*	631	645
	16*	628	637
	18	626	640
	21	622	636
	26	615	631
October	3	605	621

APPENDIX B

LIGHT INTENSITY

Each date is associated with two or more times of day each having a corresponding value of visible and infrared intensities. The latest time shown for each date represents the time of emergence. An intensity followed by an asterisk means this value was obtained by interpolation from the other values shown for that date. The date followed by an asterisk means that visible and infrared intensities at emergence were utilized in computing the correlation matrix found in the Results of this manuscript.

Date	Mountain Standard Time (P.M.)	Visible Intensity (μa)	Infrared Intensity (μa)
July 16	715	14.30	5.70
	730	4.00	1.00
	736	1.60*	.43*
	743	.53	.12
July 17	715	24.00	15.00
	730	5.00	2.70
	738	1.05*	.95*
	745	.23	.15
July 18	715	15.50	8.00
	730	4.60	3.00
	735	1.80*	1.65*
	742	.32	.13
July 20	715	33.30	13.70
	730	11.60	3.40
	732	9.30*	2.87*
	739	.70	1.45
July 21*	715	7.70	3.50
	729	2.85*	1.66*
	730	2.50	1.50
	736	.70	.25
July 22*	715	22.00	10.00
	730	10.00	4.00
	737	5.20*	1.78*
	744	.53	.20
July 23*	715	19.00	12.00
	730	1.45	.55
	732	1.12*	.43*
	739	.29	.22
July 25*	715	7.80	4.00
	729	1.50*	.53*
	730	1.36	.46
	736	.71	.27

Date	Mountain Standard Time (P.M.)	Visible Intensity (μa)	Infrared Intensity (μa)
July 30*	715	9.20	7.80
	727	1.60*	3.16*
	730	2.00	2.00
	734	.65	.40
July 31*	715	14.70	12.00
	728	3.45*	3.75*
	730	2.30	2.50
	735	.25	.20
August 1*	715	4.80	2.50
	728	2.27*	1.62*
	730	1.80	1.40
	735	.31	.16
August 3*	700	10.20	4.40
	715	2.90	.80
	716	2.66*	.73*
	723	1.35	.40
August 4*	700	13.50	3.50
	715	4.80	2.00
	718	3.57*	1.65*
	725	1.40	.45
August 6*	700	62.00	44.00
	715	25.00	20.00
	723	11.25*	3.65*
	730	1.25	.45
August 7*	700	11.30	6.00
	715	2.00	.50
	722	.38	.10
August 8*	700	21.00	11.00
	715	7.20	4.30
	720	3.30*	2.25*
	727	.70	.30
August 10*	700	7.40	2.20
	715	2.50	1.20
	719	1.66*	.88*
	726	.45	.15

Date	Mountain Standard Time (P.M.)	Visible Intensity (μa)	Infrared Intensity (μa)
August 11*	700	9.00	3.80
	715	1.12	.36
	717	.84*	.25*
	724	.24	.08
August 12*	700	14.00	4.50
	714	2.80*	1.48*
	715	2.50	1.30
	721	1.20	.40
August 13*	700	31.00	21.00
	715	6.30	7.00
	719	2.48*	4.00*
	726	.38	.23
August 14*	645	3.20	2.00
	700	3.30	3.20
	706	2.73*	2.84*
	713	.88	.62
August 15*	700	11.70	4.00
	710	3.70*	.85*
	715	1.25	.40
	717	.55	.28
August 18*	645	11.00	5.50
	700	2.80	1.00
	705	1.76*	.55*
	712	.75	.25
August 19*	645	16.00	7.50
	700	2.10	1.00
	704	1.40*	.60*
	711	.65	.25
August 20*	645	19.20	5.50
	700	6.30	1.90
	706	3.05*	1.04*
	713	1.08	.37
August 21*	645	22.00	10.00
	700	6.70	2.50
	705	3.45*	1.47*
	712	1.32	.50

Date	Mountain Standard Time (P.M.)	Visible Intensity (μa)	Infrared Intensity (μa)
August 22*	645	45.00	45.00
	700	13.50	11.00
	709	4.00*	3.00*
	716	.47	.28
August 23*	645	38.00	30.00
	700	13.00	6.50
	706	6.00*	2.03*
	713	.17	.08
August 24*	645	10.30	4.20
	700	1.45	.40
	707	.41	.13
August 25*	645	7.80	2.20
	700	1.53	.42
	707	.37	.13
August 26*	645	11.20	5.50
	658	1.75*	.55*
	700	1.35	.40
	705	.51	.16
August 27*	645	8.80	4.50
	656	2.85*	.94*
	700	1.70	.80
	703	.93	.79
August 28*	630	27.00	8.00
	645	7.20	2.00
	659	1.75*	.44*
	706	.65	.22
August 30*	630	35.00	15.00
	645	11.20	4.00
	657	2.60*	.87*
	704	.75	.30
August 31*	630	46.00	30.00
	645	11.20	7.50
	658	2.42*	1.62*
	705	.60	.30

Date	Mountain Standard Time (P.M.)	Visible Intensity (μa)	Infrared Intensity (μa)
September 1*	630	33.00	14.00
	645	8.00	3.00
	656	2.50*	.97*
	703	.72	.32
September 2*	630	27.00	16.00
	645	5.90	1.90
	653	2.44*	.78*
	700	.85	.35
September 4	615	15.00	10.00
	630	8.70	3.70
	638	5.23*	1.84*
	645	2.25	.70
September 9*	615	62.00	13.00
	630	13.10	4.70
	636	6.03*	3.05*
	643	3.30	1.70
September 11*	615	22.00	15.00
	630	5.60	2.20
	635	3.15*	1.20*
	642	1.07	.25
September 12*	615	36.00	14.00
	630	8.20	2,80
	637	3.60	1.40
September 14*	615	21.70	5.50
	630	6.50	2.70
	638	2.78*	1.37*
	645	1.04	.40
September 16*	615	17.80	5.80
	630	4.70	2.00
	637	1.80	1,00
September 18	615	15.00	6.00
	630	2.60	1,20
	633	1,64*	,83*
	640	.63	.30

Date	Mountain Standard Time (P.M.)	Visible Intensity (μa)	Infrared Intensity (μa)
September 21	615	9.70	3.00
	629	2.13*	.84*
	630	1.88	.75
	636	.75	.35
September 26	615	5.70	2.30
	624	1.58*	.66*
	631	.41	.17
October 3	600	10.00	6.00
	614	1.34*	.76*
	621	.32	.13

APPENDIX C

AMBIENT TEMPERATURE

Each date is associated with two or more times of day each having a corresponding value of temperature. The latest time shown for each date represents the time of emergence. A temperature followed by an asterisk means this value was obtained by interpolation from the other values shown for that date. The date followed by an asterisk means that temperature at emergence was utilized in computing the correlation matrix found in the Results of the manuscript.

Date	Mountain Standard Time (P.M.)	Temperature (°F)
July 16	715	100
	730	99
	736	99*
	743	98
July 17	715	99
	730	97
	738	96*
	745	95
July 18	715	98
	730	97
	735	96*
	742	95
July 20	715	94
	730	92
	732	92*
	739	92
July 21*	715	82
	729	82*
	730	82
	736	81
July 22*	715	91
	730	89
	737	89*
	744	88
July 23*	715	92
	730	90
	732	90*
	739	90
July 25*	715	93
	729	92*
	730	92
	736	90
July 27	715	94
	730	93
	733	93*
	740	92

Date	Mountain Standard Time (P.M.)	Temperature (°F)
July 30*	715	98
	727	97*
	730	97
	734	97
July 31*	715	99
	728	99*
	730	99
	735	99
August 1*	715	94
	728	92*
	730	92
	735	92
August 3*	700	75
	715	76
	716	76*
	723	75
August 4*	700	89
	715	88
	718	88*
	725	88
August 6*	700	96
	715	94
	723	92*
	730	90
August 7*	700	94
	715	92
	722	91
August 8*	700	90
	715	89
	720	89*
	727	88
August 10*	700	90
	715	93
	719	93*
	726	93

Date	Mountain Standard Time (P.M.)	Temperature (°F)
August 11*	700	91
	715	90
	717	90*
	724	90
August 12*	700	95
	714	94*
	715	94
	721	93
August 13*	700	87
	715	86
	719	86*
	726	85
August 14*	645	77
	700	76
	706	76*
	713	76
August 15*	645	88
	700	87
	710	88*
	717	88
August 18*	645	76
	700	76
	705	76*
	712	76
August 19*	645	81
	700	80
	704	80*
	711	80
August 20*	645	82
	700	79
	706	79*
	713	80
August 21*	645	90
	700	86
	705	85*
	712	84

Date	Mountain Standard Time (P.M.)	Temperature (°F)
August 22*	645	92
	700	88
	709	87*
	716	87
August 23*	645	93
	700	93
	706	92*
	713	90
August 24*	645	86
	700	85
	707	86
August 25*	645	88
	700	84
	707	84
August 26*	645	91
	658	89*
	700	89
	705	89
August 27*	645	83
	656	83*
	700	82
	703	81
August 28*	630	87
	645	84
	659	83*
	706	82
August 30*	630	96
	645	94
	657	92*
	704	90
August 31*	630	94
	645	94
	658	94*
	705	93

Date	Mountain Standard Time (P.M.)	Temperature (^{o}F)
September 1*	630	94
	645	91
	656	89*
	703	87
September 2*	630	94
	645	91
	653	89*
	700	88
September 4	615	75
	630	75
	638	75*
	645	74
September 9*	615	88
	630	87
	636	87*
	643	86
September 11*	615	84
	630	83
	635	83*
	642	82
September 12*	615	81
	630	79
	637	78
September 14*	615	80
	630	78
	638	76*
	645	74
September 16*	615	78
	630	74
	637	72
September 18	615	86
	630	86
	633	86*
	640	85

Date	Mountain Standard Time (P.M.)	Temperature (^{o}F)
September 21	615	82
	629	82*
	630	82
	636	82
September 26	615	78
	624	78*
	631	78
October 3	600	72
	614	70*
	621	69

APPENDIX D

BAROMETRIC PRESSURE

Each date is associated with two or more times of day each having a corresponding value of barometric pressure. The latest time shown for each date represents the time of emergence. A barometric pressure followed by an asterisk means this value was obtained by interpolation from the other values shown for that date. The date followed by an asterisk means that barometric pressure at emergence was utilized in computing the correlation matrix found in the Results of this manuscript. The slope represents the change (+ = increase; - = decrease) in atmospheric pressure at the Tucson International Airport during the hour interval in which emergence occurred; readings were taken hourly on the hour. The slope followed by an asterisk means that the pressure low for the evening had not been attained by the time of emergence.

Date	Mountain Standard Time (P.M.)	Barometric Pressure (Millibars)	Slope
July 21*	715	934.0	
	729	934.0*	
	730	934.0	
	736	934.0	-.005*
July 22*	715	930.5	
	730	930.5	
	737	930.6*	
	744	930.7	.000
July 23*	715	930.3	
	730	930.6	
	732	930.7*	
	739	931.0	+.035
July 25*	715	933.5	
	729	933.7*	
	730	933.7	
	736	933.8	+.010
July 27	715	929.3	
	730	929.5	
	733	929.5*	
	740	929.5	+.015
July 29	700	934.0	
	730	934.5	
	731	934.0*	
	738	934.0	+.025
July 30*	715	929.0	
	727	930.0*	
	730	930.2	
	734	930.2	+.010
July 31*	715	929.8	
	728	929.8*	
	730	929.8	
	735	930.2	+.050

Date	Mountain Standard Time (P.M.)	Barometric Pressure (Millibars)	Slope
August 1*	715	931.5	
	728	931.5*	
	730	931.5	
	735	931.5	+.040
August 3*	700	931.7	
	715	932.0	
	716	932.0*	
	723	932.0	+.015
August 4*	700	930.5	
	715	930.6	
	718	930.6*	
	725	930.6	+.005
August 6*	700	930.7	
	715	930.7	
	723	930.8*	
	730	930.8	+.015
August 7*	715	932.8	
	722	933.0	-.010
August 8*	700	930.7	
	715	930.7	
	720	930.7*	
	727	930.7	+.025
August 10*	700	932.0	
	715	932.0	
	719	932.0*	
	726	932.0	+.050
August 11*	700	934.5	
	715	934.5	
	717	934.5*	
	724	934.5	+.010
August 12*	700	933.0	
	714	933.1*	
	715	933.1	
	721	933.2	+.020

Date	Mountain Standard Time (P.M.)	Barometric Pressure (Millibars)	Slope
August 13*	700	931.0	
	715	931.0	
	719	931.0*	
	726	931.0	+.025
August 14*	645	933.2	
	700	933.2	
	706	933.3*	
	713	933.5	-.010
August 15*	645	933.7	
	700	934.0	
	710	934.2*	
	717	934.3	+.015
August 18*	645	934.5	
	700	934.5	
	705	934.6*	
	712	934.7	.000
August 19*	645	934.7	
	700	935.0	
	704	935.0*	
	711	935.1	+.020
August 20*	645	933.0	
	700	933.0	
	706	933.0*	
	713	933.0	+.020
August 21*	645	931.0	
	700	931.1	
	705	931.1*	
	712	931.2	+.010
August 22*	645	931.9	
	700	932.6	
	709	932.7*	
	716	932.8	+.045

Date	Mountain Standard Time (P.M.)	Barometric Pressure (Millibars)	Slope
August 23*	645	932.8	
	700	932.8	
	706	933.0*	
	713	933.2	+.015
August 24*	700	931.4	
	707	931.6	+.020
August 25*	700	931.8	
	707	931.7	+.025
August 26*	645	933.6	
	658	934.0*	
	700	934.0	
	705	934.2	+.015
August 27*	630	933.4	
	645	933.5	
	656	933.6*	
	703	933.7	+.010
August 28*	630	930.0	
	645	930.2	
	659	930.1*	
	706	930.1	+.010
August 30*	630	629.5	
	645	929.7	
	657	929.9*	
	704	930.0	+.020
August 31*	630	930.9	
	645	931.0	
	658	931.2*	
	705	931.3	+.015
September 1*	630	929.0	
	645	929.0	
	656	929.0*	
	703	929.0	+.005

Date	Mountain Standard Time (P.M.)	Barometric Pressure (Millibars)	Slope
September 2*	630	929.7	
	645	929.8	
	653	929.8*	
	700	929.8	+.018
September 4	615	931.8	
	630	931.8	
	638	931.8*	
	645	931.8	-.020*
September 9*	615	932.5	
	630	932.6	
	636	932.7*	
	643	932.9	+.010
September 11*	615	931.2	
	630	931.2	
	635	931.2*	
	642	931.3	+.010
September 12*	630	929.4	
	637	929.5	
September 14*	615	931.7	
	630	931.7	
	638	931.6*	
	645	931.6	.000
September 16*	630	934.5	
	637	934.5	+.010
September 18	615	932.3	
	630	932.0	
	633	931.9*	
	640	931.8	.000
September 21	615	929.0	
	629	929.0*	
	630	929.0	
	636	929.0	+.005

Date	Mountain Standard Time (P.M.)	Barometric Pressure (Millibars)	Slope
September 26	615	936.4	
	624	936.5*	
	631	936.6	+.010
October 3	600	934.7	
	614	934.9*	
	621	935.0	+.010

APPENDIX E

AMBIENT RELATIVE HUMIDITY

Each date is associated with two or more times of day each having a corresponding value of % RH. The latest time shown for each date represents the time of emergence. A % RH followed by an asterisk means this value was obtained by interpolation from the other values shown for that date. The date followed by an asterisk means that % RH at emergence was utilized in computing the correlation matrix found in the Results of this manuscript.

Date	Mountain Standard Time (P.M.)	% RH
July 16	715	10.5
	730	11.5
	736	11.5*
	743	11.0
July 17	715	10.0
	730	10.5
	738	11.5*
	745	15.0
July 18	715	13.0
	730	14.0
	735	15.0*
	742	17.0
July 20	715	26.5
	730	28.0
	732	28.0*
	739	28.5
July 21*	715	60.0
	729	66.5*
	730	67.0
	736	70.0
July 22*	715	25.0
	730	26.0
	737	27.0*
	744	28.0
July 23*	715	22.5
	730	22.0
	732	22.0*
	739	22.0
July 25	715	18.0
	729	19.0*
	730	19.0
	736	21.0
July 27	715	18.0
	730	18.0
	733	18.5*
	740	19.0

Date	Mountain Standard Time (P.M.)	% RH
July 30*	715	10.0
	727	11.5*
	730	12.0
	734	35.0
July 31*	715	12.0
	728	13.0*
	730	13.0
	735	12.0
August 1*	715	13.5
	728	14.5*
	730	14.5
	735	15.0
August 3*	700	91.0
	715	92.0
	716	92.0*
	723	94.5
August 4*	700	27.0
	715	29.0
	718	29.5*
	725	30.0
August 6*	700	21.5
	715	30.5
	723	33.0*
	730	35.0
August 7*	715	27.0
	722	29.0
August 8*	700	27.0
	715	29.0
	720	29.5*
	727	30.0
August 10*	700	20.5
	715	20.0
	719	20.0*
	726	20.0

Date	Mountain Standard Time (P.M.)	% RH
August 11*	700	24.5
	715	26.5
	717	27.0*
	724	29.0
August 12*	700	21.0
	714	22.0*
	715	22.0
	721	23.0
August 13*	700	77.0
	715	82.5
	719	82.5*
	726	83.0
August 14*	645	85.0
	700	77.0
	706	80.0*
	713	84.0
August 15*	645	33.0
	700	36.0
	710	38.0*
	717	39.0
August 18*	645	79.0
	700	83.5
	705	82.5*
	712	80.5
August 19*	645	46.0
	700	47.0
	704	47.5*
	711	48.0
August 20*	645	46.0
	700	54.0
	706	57.0*
	713	61.0
August 21*	645	19.0
	700	26.0
	705	27.5*
	712	29.5

Date	Mountain Standard Time (P.M.)	% RH
August 22*	645	13.5
	700	18.0
	709	19.0*
	716	19.5
August 23*	645	17.0
	700	16.0
	706	15.5*
	713	15.0
August 24*	700	27.0
	707	20.0
August 25*	700	16.0
	707	16.5
August 26*	645	19.0
	658	21.5*
	700	22.0
	705	23.0
August 27*	630	24.0
	645	28.0
	656	32.5*
	703	35.0
August 28*	630	06.0
	645	06.0
	659	07.0*
	706	07.0
August 30*	630	07.0
	645	08.0
	657	09.5*
	704	10.0
August 31*	630	07.5
	645	08.0
	658	08.0*
	705	08.0

Date	Mountain Standard Time (P.M.)	% RH
September 1*	630	06.0
	645	08.0
	656	08.5*
	703	09.0
September 2*	630	07.0
	645	08.5
	653	09.5*
	700	09.0
September 4	615	65.0
	630	71.0
	638	73.0*
	645	75.0
September 9*	615	34.5
	630	34.0
	636	35.5*
	643	37.0
September 11*	615	40.0
	630	44.0
	635	45.0*
	642	46.0
September 12*	630	43.0
	637	45.0
September 14*	615	18.0
	630	21.0
	638	25.5*
	645	29.0
September 16*	630	11.5
	637	14.0
September 18	615	08.0
	630	08.0
	633	08.0*
	640	08.0

Date	Mountain Standard Time (P.M.)	% RH
September 21	615	18.0
	629	19.0*
	630	19.0
	636	19.0
September 26	615	08.0
	624	08.0*
	631	08.0
October 3	600	31.0
	614	34.5*
	621	36.0

APPENDIX F

CAVE TEMPERATURE

Each date is associated with two or more times of day each having a corresponding value of millivolts. The latest time shown for each date represents the time of emergence. Millivolts followed by an asterisk means this value was obtained by interpolation from the other values shown for that date. The date followed by an asterisk means that cave temperature at emergence was utilized in computing the correlation matrix found in the Results of this manuscript. The reference junction temperature is equivalent to ambient temperature.

Date	Mountain Standard Time (P.M.)	Potentiometer (Millivolts)	Reference Junction Temperature (^{o}F)	Cave Temperature (^{o}F)
July 16	715	-.77		
	730	-.74		
	736	-.74*	99	67
	743	-.74	98	65
July 17	715	-.73		
	730	-.72		
	738	-.70*	96	65
	745	-.67	95	65
July 18	715	-.74		
	730	-.70		
	735	-.69*	96	66
	742	-.66	95	66
July 20	715	-.64		
	730	-.61		
	732	-.61*	92	65
	739	-.61	92	65
July 21*	715	-.38		
	729	-.36*	82	66
	730	-.36		
	736	-.36	81	65
July 22*	715	-.56		
	730	-.53		
	737	-.51*	89	66
	744	-.49	88	66
July 23*	715	-.60		
	730	-.56		
	732	-.56*	90	65
	739	-.56	90	65
July 25*	715	-.60		
	729	-.60*	92	66
	730	-.60		
	736	-.60	90	63

Date	Mountain Standard Time (P.M.)	Potentiometer (Millivolts)	Reference Junction Temperature (^{o}F)	Cave Temperature (^{o}F)
July 27	715	-.63		
	730	-.60		
	733	-.59*	93	67
	740	-.56	92	67
July 30*	715	-.75		
	727	-.72*	97	65
	730	-.72		
	734	-.72	97	65
July 31*	715	-.78		
	728	-.76*	99	66
	730	-.76		
	735	-.76	99	66
August 1*	715	-.65		
	728	-.61*	92	65
	730	-.61		
	735	-.61	92	65
August 3*	700	-.19		
	715	-.19		
	716	-.19*	76	68
	723	-.18	75	67
August 4*	700	-.52		
	715	-.48		
	718	-.47*	88	67
	725	-.46	88	68
August 6*	700	-.72		
	715	-.66		
	723	-.63*	92	64
	730	-.60	90	63
August 7*	700	-.62		
	715	-.58	92	66
	722	-.58	91	65

Date	Mountain Standard Time (P.M.)	Potentiometer (Millivolts)	Reference Junction Temperature (^{o}F)	Cave Temperature (^{o}F)
August 8*	700	-.54		
	715	-.50		
	720	-.49*	89	67
	727	-.47	88	67
August 10*	700	-.53		
	715	-.58		
	719	-.59*	93	67
	726	-.60	93	67
August 11*	700	-.56		
	715	-.55		
	717	-.55*	90	66
	724	-.54	90	66
August 12*	700	-.66		
	714	-.64*	94	66
	715	-.64		
	721	-.62	93	66
August 13*	700	-.50		
	715	-.46		
	719	-.45*	86	66
	726	-.44	85	65
August 14*	645	-.27		
	700	-.26		
	706	-.25*	76	65
	713	-.22	76	66
August 15*	645	-.50		
	700	-.46		
	710	-.44*	88	69
	717	-.43	88	69
August 18*	645	-.22		
	700	-.22		
	705	-.22*	76	66
	712	-.20	76	67

Date	Mountain Standard Time (P.M.)	Potentiometer (Millivolts)	Reference Junction Temperature (°F)	Cave Temperature (°F)
August 19*	645	-.34		
	700	-.30		
	704	-.30*	80	67
	711	-.30	80	67
August 20*	645	-.30		
	700	-.30		
	706	-.30*	79	66
	713	-.29	80	67
August 21*	645	-.56		
	700	-.48		
	705	-.46*	85	65
	712	-.44	84	64
August 22*	645	-.58		
	700	-.54		
	709	-.52*	87	64
	716	-.50	87	65
August 23*	645	-.59		
	700	-.59		
	706	-.59*	92	66
	713	-.57	90	65
August 24*	700	-.40	85	67
	707	-.40	86	68
August 25*	700	-.42	84	65
	707	-.40	84	66
August 26*	645	-.58		
	658	-.54*	89	65
	700	-.53		
	705	-.52	89	66
August 27*	645	-.35		
	656	-.33*	83	68
	700	-.33		
	703	-.33	81	66

Date	Mountain Standard Time (P.M.)	Potentiometer (Millivolts)	Reference Junction Temperature (^{o}F)	Cave Temperature (^{o}F)
August 28*	630	-.37		
	645	-.38		
	659	-.36*	83	67
	706	-.32	82	68
August 30*	630	-.64		
	645	-.60		
	657	-.57*	92	67
	704	-.54	90	66
August 31*	630	-.60		
	645	-.60		
	658	-.59*	94	68
	705	-.57	93	68
September 1*	630	-.65		
	645	-.57		
	656	-.53*	89	66
	703	-.51	87	64
September 2*	630	-.61		
	645	-.59		
	653	-.57*	89	64
	700	-.54	88	64
September 4	615	-.20		
	630	-.20		
	638	-.19*	75	67
	645	-.17	74	66
September 9*	630	-.46		
	636	-.46*	87	67
	643	-.45	86	66
September 11*	615	-.37		
	630	-.37		
	635	-.36*	83	67
	642	-.34	82	67

Date	Mountain Standard Time (P.M.)	Potentiometer (Millivolts)	Reference Junction Temperature (^{o}F)	Cave Temperature (^{o}F)
September 12*	630	-.30	79	66
	637	-.28	78	66
September 14*	615	-.26		
	630	-.26		
	638	-.24*	76	65
	645	-.20	74	65
September 16*	615	-.23		
	630	-.18	74	66
	637	-.15	72	65
October 3	600	-.18		
	614	-.13*	70	64
	621	-.10	69	65

APPENDIX G

CAVE RELATIVE HUMIDITY

Each date is associated with two or more times of day each having a corresponding value of impedance. The latest time shown for each date represents the time of emergence. An impedance followed by an asterisk means this value was obtained by interpolation from the other values shown for that date. The date followed by an asterisk means that % RH at emergence was utilized in computing the correlation matrix found in the Results of this manuscript.

Date	Mountain Standard Time (P.M.)	Sensor Impedance (1000 ohms)	% RH (indicated)
July 16	715	47	
	730	44	
	736	45*	104
	743	47	102
July 17	715	49	
	730	48	
	738	49*	102
	745	50	101
July 18	715	53	
	730	51	
	735	51*	101
	742	50	101
July 20	715	51	
	730	51	
	732	51*	101
	739	49	102
July 21*	715	52	
	729	51*	101
	730	51	
	736	51	101
July 22*	715	50	
	730	47	
	737	46*	103
	744	46	103
July 23*	715	41	
	730	41	
	732	41*	104
	739	41	104
July 25*	715	49	
	729	48*	102
	730	48	
	736	48	103

Date	Mountain Standard Time (P.M.)	Sensor Impedance (1000 ohms)	% RH (indicated)
July 27	715	45	
	730	45	
	733	45*	104
	740	46	103
July 30*	715	49	
	727	49*	102
	730	49	
	734	49	102
July 31*	715	48	
	728	48*	102
	730	48	
	735	47	102
August 1*	715	52	
	728	51*	101
	730	51	
	735	50	101
August 3*	700	48	
	715	50	
	716	50*	101
	723	47	102
August 4*	700	50	
	715	48	
	718	48*	102
	725	49	102
August 6*	700	52	
	715	51	
	723	52*	102
	730	53	102
August 7*	700	53	
	715	52	101
	722	53	101
August 8*	700	51	
	715	52	
	720	52*	101
	727	51	101

Date	Mountain Standard Time (P.M.)	Sensor Impedance (1000 ohms)	% RH (indicated)
August 10*	700	54	
	715	54	
	719	54*	100
	726	54	100
August 11*	700	52	
	715	53	
	717	53*	101
	724	51	101
August 12*	700	51	
	714	54*	100
	715	54	
	721	52	101
August 13*	700	54	
	715	51	
	719	51*	101
	726	50	101
August 14*	645	52	
	700	51	
	706	52*	101
	713	53	101
August 15*	645	53	
	700	54	
	710	52*	101
	717	50	101
August 18*	645	52	
	700	50	
	705	50*	101
	712	50	101
August 19*	645	50	
	700	50	
	704	50*	101
	711	49	102
August 20*	645	58	
	700	57	
	706	55*	100
	713	50	101

Date	Mountain Standard Time (P.M.)	Sensor Impedance (1000 ohms)	% RH (indicated)
August 21*	645	50	
	700	52	
	705	53*	101
	712	55	101
August 22*	645	58	
	700	55	
	709	52*	102
	716	49	102
August 23*	645	54	
	700	52	
	706	53*	101
	713	54	100
August 24*	645	58	
	700	62	98
	707	56	100
August 25*	645	56	
	700	53	101
	707	59	99
August 26*	645	57	
	658	60*	99
	700	60	
	705	62	98
August 27*	630	68	
	645	63	
	656	61*	99
	703	60	99
August 28*	630	73	
	645	70	
	659	68*	97
	706	67	97
August 30*	630	92	
	645	85	
	657	83*	94
	704	84	94

Date	Mountain Standard Time (P.M.)	Sensor Impedance (1000 ohms)	% RH (indicated)
August 31*	630	83	
	645	84	
	658	84*	94
	705	83	94
September 1*	630	82	
	645	85	
	656	84*	94
	703	82	95
September 2*	630	93	
	645	91	
	653	90*	94
	700	90	94
September 9*	615	64	
	630	58	
	636	56*	100
	643	53	101
September 11*	615	62	
	630	66	
	635	65*	98
	642	62	98
September 12*	615	69	
	630	65	98
	637	61	99
September 14*	615	82	
	630	79	
	638	77*	96
	645	74	96
September 16*	615	87	
	630	82	94
	637	85	94
October 3	600	84	
	614	88*	95
	621	90	93

APPENDIX H

WIND VELOCITY AND HEADING

Velocities and headings are values at emergence. The date followed by an asterisk means that velocity at emergence was utilized in computing the correlation matrix found in the Results of this manuscript.

Date	Velocity (ft./min.)	Heading (degrees magnetic)
16 July	50	360
17	00	---
18	00	---
20	400	80
21*	00	---
22*	50	90
23*	00	---
25*	00	---
27	100	90
29	00	---
30*	400	30
31*	250	180
1* August	00	---
3*	00	---
4*	400	260
5	00	---
6*	00	---
7*	200	360
8*	00	---
10*	250	250
11*	00	---
12*	250	90
13*	00	---
14*	300	270
15*	00	---
18*	100	260
19*	00	---
20*	00	---
21*	00	---
22*	500	260
23*	250	250
24*	00	---
25*	150	270
26*	00	---
27*	00	---
28*	00	---
30*	00	---
31*	150	360

Date	Velocity (ft./min.)	Heading (degrees magnetic)
1* September	00	---
2*	250	60
4	00	---
9*	00	---
11*	00	---
12*	00	---
14*	00	---
16*	00	---
18	400	90
21	400	90
26	300	270
3 October	00	---

APPENDIX 1

STATISTICS

1. Legend for Items 2 through 11

a = Y intercept of linear regression line.

b = slope of linear regression line.

$\bar{d}$ = mean difference between paired measurements.

d.f. = degrees of freedom.

F = ratio of variances.

H_o = hypothesis.

N = number of observations.

r = linear correlation coefficient.

S^2 = variance of sample.

σ^2 = variance of population.

S = standard deviation of sample.

$S_{\bar{X}}$ = standard error of sample mean.

S^2_d = variance of the differences between paired measurements.

$Sy.x$ = standard error of estimate of Y.

t = Student's distribution.

μ = mean of population.

V = coefficient of variation.

X = any given value of the variate.

$\bar{X}$ = arithmetic mean of sample.

Y = any given value of the variate.

$\bar{Y}$ = arithmetic mean of sample.

Y est. = estimate of Y.

Σ = all the data represented by the symbol or symbols following it are to be added together.

Items 2 through 10 are from Simpson, Roe and Lewontin (1960) and item 11 is from Spiegel (1961).

2. Arithmetic Mean

$$\bar{X} = \frac{\Sigma X}{N}$$

3. Standard Error of the Mean

$$S_{\bar{X}} = \frac{S}{\sqrt{N}}$$

4. Variance

$$S^2 = \frac{\Sigma (X-\bar{X})^2}{N-1}$$

5. Standard Deviation

$$S = \sqrt{\frac{\Sigma (X-\bar{X})^2}{N-1}}$$

6. Ratio of Variances

$$F = \frac{S_1^2}{S_2^2}$$

$$H_o: \frac{\sigma_1^2}{\sigma_2^2} = 1$$

d.f. = N - 1 for both S_1^2 and S_2^2

7. Coefficient of Variation

$$V = \frac{100\ S}{\bar{X}}$$

$$\text{confidence interval} = V \pm t \frac{V}{\sqrt{2N}}$$

d.f. = N - 1

8. Paired t-Test for the Difference between the Means

$$t = \frac{\bar{d}}{\sqrt{\frac{S_d^2}{N}}}$$

H_o: μ (of the differences) = 0

d.f. = N - 1

9. Linear Regression of Y on X

$Y = a + b X$

Y = dependent variable

X = independent variable

$a = \overline{Y} - b \overline{X}$

$$b = \frac{\Sigma (X-\overline{X}) (Y-\overline{Y})}{\Sigma (X-\overline{X})^2}$$

10. Linear Correlation Coefficient

$$r = \frac{\Sigma (X-\overline{X}) (Y-\overline{Y})}{\sqrt{\Sigma (X-\overline{X})^2 \; \Sigma (Y-\overline{Y})^2}}$$

11. Standard Error of Estimate

$$Sy.x = \sqrt{\frac{\Sigma (Y-Y \text{ est.})^2}{N - 2}}$$

REFERENCES CITED

Allison, Vernon C. 1937. Evening bat flight from Carlsbad Caverns. J. Mammal., 18(1):80-82.

Brown, Frank A., Jr. 1960. Response to pervasive geophysical factors and the biological clock problem. Cold Spring Harbor Symposia on Quantitative Biology, 25:57-71.

Church, H. F. 1957. The times of emergence of the pipistrelle. Proc. Zool. Soc. London, 128:600-602.

Cloudsley-Thompson, J. L. 1960. Adaptive functions of circadian rhythms. Cold Spring Harbor Symposia on Quantitative Biology, 25:345-355.

Constantine, Denny G. 1967. Activity patterns of the Mexican free-tailed bat. Univ. New Mexico Publ. in Biol., No. 7, Univ. New Mexico Press.

Cutter, William L. 1955. Notes on the behavior of the red bat (Lasiurus borealis). Acad. Sci. for 1955, p. 51.

DeCoursey, George and Patricia J. DeCoursey. 1964. Adaptive aspects of activity rhythms in bats. Biol. Bull., 126(1):14-27.

DeCoursey, Patricia J. 1960. Phase control of activity in a rodent. Cold Spring Harbor Symposia on Quantitative Biology, 25:49-55.

Dwyer, P. D. 1964. Seasonal changes in activity and weight of Miniopterus schreibersi blepotis (Chiroptera) in North-Eastern New South Wales. Austr. J. Zool., 12(1):52-69.

Finley, Robert B., Jr. 1959. Observation of nocturnal animals by red light. J. Mammal., 40(4):591-594.

Gould, Patrick J. 1961. Emergence of Tadarida in relation to light intensity. J. Mammal., 42(3):405-407.

Greenhall, Arthur M. 1961. Storm forecasting by bats. J. Trinidad Field Nat. Club, July.

Hayward, Bruce J. 1970. The natural history of the cave bat *Myotis velifer*. Res. Comm. Western New Mexico Univ., 1(1):74.

Herreid, Clyde F., II. 1963. Survival of a migratory bat at different temperatures. J. Mammal., 44(3): 431-433.

Herreid, Clyde F., II. and Richard B. Davis. 1966. Flight patterns of bats. J. Mammal., 47(1):78-86.

Herreid, Clyde F., II. and Knut Schmidt-Nielsen. 1966. Oxygen consumption, temperature, and water loss in bats from different environments. Amer. J. Physiol., 211(5):1108-1112.

Krutzsch, Philip H. 1955. Observations on the Mexican free-tailed bat, *Tadarida mexicana*. J. Mammal., 36(2):236.

Licht, Paul and Philip Leitner. 1967. Physiological responses to high environmental temperatures in three species of microchiropteran bats. Comp. Biochem. Physiol., 22:371-387.

Lowe, Charles H. 1964. The Vertebrates of Arizona. Univ. Ariz. Press, Tucson, Ariz., 270 pp.

Miller, Jerome Stapleton. 1955. A study of the roosting habits, and of the environmental factors concurrent with time of evening flight, of little brown bats (*Myotis lucifugus*) in northern lower Michigan. Diss. Abstr., 15(1):647.

Mitchell, Donald F. and Carl Epling. 1951. The diurnal periodicity of *Drosophila pseudoobscura* in southern California. Ecology, 32(4):696-708.

Orr, Robert T. 1954. Natural history of the pallid bat, *Antrozous pallidus* (Le Conte). Proc. Calif. Acad. Sci., 28(4):165-246.

Phillips, Gary L. 1966. Ecology of the big brown bat (Chiroptera : Vespertilionidae) in northern Kansas. Amer. Midl. Nat., 75(1):168-198.

Prakash, Ishwar. 1962. Times of emergence of the pipistrelle. Mammalia, 26(1):133-135.

Procter, John W. and Eugene H. Studier. 1970. Effects of ambient temperature and water vapor pressure on evaporative water loss in Myotis lucifugus. J. Mammal., 51(4):799-804.

Provost, Ernest E. and Charles M. Kirkpatrick. 1952. Observations on the hoary bat in Indiana and Illinois. J. Mammal., 33(1):110-113.

Rice, Dale W. 1957. Life history and ecology of Myotis austroriparius in Florida. J. Mammal., 38(1): 15-32.

Schoennagel, Erich. 1963. Der Abendflug der stockente und seine Abhärgigkeit von der Lichtintensität. Proc. Int. Ornithol. Congr., 13:293-298.

Sharp, Ward M. and Louise H. Sharp. 1956. Nocturnal movements and behavior of wild raccoons at a winter feeding station. J. Mammal., 37(2):170-177.

Simpson, George Gaylord, Anne Roe and Richard C. Lewontin. 1960. Quantitative Zoology. Harcourt, Brace and World, Inc., New York. 440 pp.

Spiegel, Murray R. 1961. Theory and problems of statistics. Schaum Publishing Company, New York. 359 pp.

Stebbings, R. E. 1968. Measurements, composition and behavior of a large colony of the bat Pipistrellus pipistrellus. J. Zool., 156:15-33.

Tables at Sunrise, Sunset, and Twilight. 1945. Nautical Almanac Office, U. S. Naval Observatory, U. S. Government Printing Office, Wash. D. C. 196 pp.

Twente, John W., Jr. 1955. Some aspects of habitat selection and other behavior of cavern-dwelling bats. Ecology, 36(4):706-732.

Twente, John W., Jr. 1956. Ecological observations of a colony of Tadarida mexicana. J. Mammal., 37(1): 42-47.

Vaughan, Terry A. 1959. Functional morphology of three bats: Eumops, Myotis, Macrotus. Univ. Kan. Publ. Mus. Natur. Hist., 12(1):1-153.

Venables, L. S. V. 1943. Observations at a pipistrelle bat roost. J. Anim. Ecol., 12(1):19-26.

Walls, Gordon Lynn. 1942. The Vertebrate Eye and its Adaptive Radiation. Cranbrook Inst. Sci., Bull. No. 19. 785 pp.

Williams, C. B. 1940. An analysis of four years captures of insects in a light trap. Part II. The effect of weather conditions on insect activity; and the estimation and forecasting of changes in the insect population. Trans. Roy. Entomol. Soc., 90:227-306.