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METEOROLOGICAL EFFECTS ON THE BITING ACTIVITY OF *LEPTOCONOPS AMERICANUS* (DIPTERA: CERATOPOGONIDAE)[1]

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ABSTRACT. Collections of biting *Leptoconops americanus* were made at half-hour intervals throughout the daylight hours on Stansbury Island, UT, during 9 days in May, 1993. The most favorable conditions for biting (≥90 bites on the ears in 15 min) included temperatures higher than 15°C, minimum wind (<5 kph), minimum cloud cover, maximum sun, and no rain. Temperatures below 10°C or the presence of rain prevented almost all biting. Higher winds and cloudiness decreased biting activity, but did not eliminate it if other conditions were favorable. Although not statistically significant, there was some suggestion from the data that higher temperatures (>25°C) reduced biting. The flies did not appear to be more numerous at any particular part of the day; the biting rate simply followed meteorological conditions at the time. Ambient light varied between 1 and 10,000 foot candles during the study, with high biting rates (76 and 99 bites per 15 min) observed at levels as low as 80–100 foot candles.

INTRODUCTION

The genus *Leptoconops* includes a number of diurnally biting species in various parts of the world. The immediate effects of a bite are considered less severe than the subsequent lesion that can result (e.g., Whitsel and Schoeppner 1966). These lesions were described pathologically by Steffen (1981), who examined patients following a particularly severe infestation of *Leptoconops torrens* (Townsend) at Palm Springs, CA. He noted indurated papules, which could remain intensely itching for months and which he observed histologically as long as one month after the bite. Aussel (1993) claimed that the bite from *Leptoconops albiventris* de Meijere in French Polynesia often became infected, resulting in general edema and lymphadenopathy.

As a result of their larval habitats on beaches, a number of tropical species of *Leptoconops* have been mentioned as a significant problem for the tourist industry in the Caribbean region (*Leptoconops bequaerti* (Kieffer) [Linley and Davies 1971]), French Polynesia (*L. albiventris* [Aussel 1993]), southern Japan (*Leptoconops nipponensis* (Tokunaga) [Matayoshi et al. 1985]), the Philippines (*Leptoconops spinosifrons* Carter [Takaoka et al. 1976]), and elsewhere. In the western United States, inland species such as *Leptoconops carteri* Hoffman (as *L. torrens* in Whitsel and Schoeppner 1966), *Leptoconops foulki* Clastrier and Wirth (Foulk 1966), *Leptoconops knowltoni* Clastrier and Wirth (Brenner et al. 1984a), and *Leptoconops americanus* Carter (Rees and Smith 1950, Rees et al. 1969, Rees and Winget 1970) can be very abundant, disrupting outdoor activities.

During studies of repellents (Perich et al. 1995) on Stansbury Island in the Great Salt Lake of Utah, we recorded the biting rate of *L. americanus* in relation to meteorological conditions.

MATERIALS AND METHODS

The study site was at the base of the hills on the western side of Stansbury Island in the Great Salt Lake, Tooele County, UT. This part of the island is privately owned, uninhabited, and used for grazing cattle and outdoor recreational activities. The beach at this location extends for a kilometer as a stretch of extremely briny sand dotted with sparse, salt-tolerant plants (salt grass, *Distichlis stricta*; glasswort, *Salicornia rubra*; pickelweed, *Allenrolfea occidentalis*; and foxtail barley, *Hordeum jubatum*). The soil at the bases of these clumps of plants is the primary larval habitat of the biting midges in this area.[2] The vegetation becomes much taller (up to 2 m) and thicker at the inland edge of the beach, then more sparse and grassy on the slopes of hills where cattle graze. Our collection sites were located in the thick vegetation or in the grassy areas, 200–500 m from the larval habitat.

Collections were made each 30 min from shortly after dawn (0700 h) to dusk, on May 4

[1] Opinions and assertions contained herein are solely those of the authors and do not purport to reflect the positions of the Departments of Defense or Army.

[2] Rees, D. M., R. N. Winget and P. G. Laywer. 1970. Studies in Utah of the biting gnat *Leptoconops kerteszi* Kieffer (Diptera: Ceratopogonidae). Final Report, Contract No. DADA 17-69-C-905-P003. U.S. Army Medical Research and Development Command, Washington, DC.

through May 12, 1993. Preliminary collections had indicated that no gnats were biting before dawn or after sunset. Flies were captured from a volunteer dressed in the military "Battle Dress Uniform" in forest camouflage. Because the flies favored the ears and to reduce biting on other exposed areas, volunteers covered their heads with nylon stocking, with their ears protruding from 2 small holes in the fabric. A collector protected by clothing and a fine-mesh head net aspirated midges biting the ears of the volunteer (Perich et al. 1994). The collection continued for 15 min or until at least 20 flies had been captured, whichever came first. The collection aspirator had been modified to increase suction by inserting a plastic pipette tip with its aperture widened to approximately 3 mm. All midges were blown into permethrin-treated cartons after capture, resulting in rapid knockdown. Flies were counted in the field, then preserved in alcohol for subsequent identification (Wirth and Atchley 1973, Clastrier and Wirth 1978).

The following meteorological measurements were made before each collection: dry and wet bulb temperatures; highest and lowest wind speeds during 90 sec; cloudiness gauged as none, partial, or complete; sun exposure gauged as none (when obscured by heavy overcast), partial (when covered by thin overcast), intermittent, or constantly sunny; and occurrence of rain gauged as none, trace, or raining. Maximum and minimum light levels were recorded during a 90-sec interval using a hand-held, directional light meter pointed straight upwards while facing the sun.

Data were analyzed on the basis of flies biting per 15 min. When biting rates were high, collections were terminated after capturing approximately 20 flies and time elapsed recorded. For the purposes of analysis, the results of such collections were adjusted to the number of flies that would have bitten in 15 min. SPSS/PC+ 4.0 statistics software (SPSS Inc., Chicago, IL) was used to perform statistical tests. Early in the analysis it was determined that the data were not normally distributed and that variances between categories of interest (e.g., variance of the mean number of flies captured at one temperature interval compared to variance at another temperature interval) were not equal, even following log transformation. We used 2 kinds of nonparametric tests to determine whether there were significant differences between ranges of meteorological factors: comparison of number of observations above and below the median value and Kruskal-Wallis one-way analysis of variance based on ranks (i.e., the magnitude of an observation relative to all other observations, expressed as an integer between one and the total number of observations). Both tests used an approximation of χ^2 to evaluate whether significant differences existed between categories.

The test of difference from the median and the Kruskal-Wallis test of ranks established the relationship of biting rate to single meteorological factors. The influence of interaction of meteorological factors on biting rates would normally be examined by multiple regression, but in this study the distribution of the data precluded the use of this approach. In order to gain an understanding of the influence of interaction of meteorological factors, the data were categorized by level of biting rate and then compared to the mean meteorological values for that level of biting. In this way, the mean meteorological factors could be compared among each other for a given intensity of biting.

Finally, data were examined graphically to determine variation in diel patterns of biting. Data were combined for the days on which biting rates were low, because individual days did not differ much from the general pattern. Data were graphed for each individual day when biting rates were high, because each of those days demonstrated a different diel pattern.

RESULTS

Preliminary analyses allowed us to eliminate minimum wind speed and relative humidity as relevant to biting rates observed during the study. Light levels were difficult to measure consistently and were not correlated to biting rate ($r^2 = 0.014$). Biting rates were high on 2 occasions when light levels were low, biting at a rate of 99/per 15 min on May 10 at 2030 h with light between 80 and 100 foot candles and at a rate of 76 per 15 min on May 12 with light between 80 and 90 foot candles. The median light level during the day was between 3,000 and 4,000 foot candles and the maximum level observed was 10,000 foot candles.

The number of biting flies was greatest during warmer, less windy, sunnier periods based both on analysis of ranks of observations and on comparisons of observations with the median (Table 1). Biting was consistently low at temperatures below 10°C and was moderate between 10 and 15°C. At all temperatures above 15°C, biting was more often above the median than below it and mean ranks were much greater than 108, the middle rank for all observations (i.e., one-half the total number of 217 observations). Maximum biting rates were observed when the wind speed was below 1 kph. From 1 to 5 kph, mean ranks were above 108 and the majority of observations were greater than the median, but above 5 kph biting decreased progressively with increasing wind speed. Increased sun exposure,

Table 1. Comparison of biting rate by *Leptoconops americanus* by time of day, temperature, wind speed, sun exposure, cloud cover, and rainfall at the time of collection. Intervals are compared by mean rank of cases ($n = 217$) for number of flies biting per 15 min and by the number of times observations were above or below the median (median = 5 bites per 15 min).

Interval	Mean bites per 15 min	Mean rank of observations	No. of cases compared to median: Greater	Less
Time of day (h)[1]				
0700–0959	28.9	96.1	15	25
1000–1159	24.1	94.6	12	25
1200–1359	12.0	96.3	15	20
1400–1559	20.0	117.7	23	13
1600–1759	26.5	126.6	20	11
1800–1959	32.3	134.8	19	7
2000–2159	38.4	105.9	4	8
Temperature (°C)[2]				
5–9.9	0.03	42.9	0	32
10–14.9	7.2	78.5	22	67
15–19.9	46.2	152.7	32	6
20–24.9	65.5	172.9	23	3
25–29	37.8	156.1	31	1
Wind (kph)[3]				
<1	59.3	164.0	10	1
1–2.9	35.7	130.6	29	20
3–4.9	24.8	118.2	38	24
5–6.9	21.9	104.5	19	20
7–8.9	12.0	76.0	9	26
9–20	4.8	66.1	3	18
Sun[4]				
Obscured	2.4	52.7	3	45
Partial	0.1	47.2	0	16
Intermittent	9.8	96.0	10	21
Exposed	40.1	142.5	95	27
Clouds[5]				
None	45.5	151.9	79	15
Partial	13.6	94.6	28	47
Complete	0.3	47.5	1	47
Rain[6]				
None	28.1	118.4	108	81
Trace	0.3	50.2	0	12
Rain	0	41.5	0	16

[1] Kruskal-Wallis one-way ANOVA for mean ranks (KW): $\chi^2 = 12.6$, $P = 0.0497$; Median test (MT): $\chi^2 = 20.0$, $P < 0.01$.
[2] KW $\chi^2 = 119.9$, $P < 0.01$; MT $\chi^2 = 116.0$, $P < 0.01$.
[3] KW $\chi^2 = 35.2$, $P < 0.01$; MT $\chi^2 = 31.2$, $P < 0.01$.
[4] KW $\chi^2 = 90.2$, $P < 0.01$; MT $\chi^2 = 94.6$, $P < 0.01$.
[5] KW $\chi^2 = 93.9$, $P < 0.01$; MT $\chi^2 = 92.5$, $P < 0.01$.
[6] KW $\chi^2 = 33.3$, $P < 0.01$; MT $\chi^2 = 31.9$, $P < 0.01$.

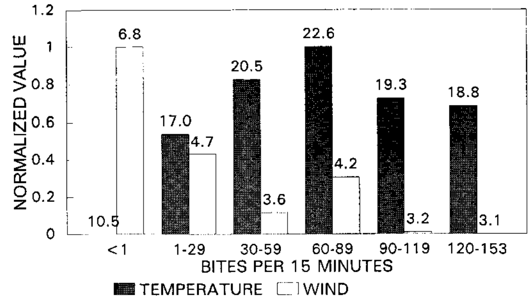

Fig. 1. Mean temperature and wind (normalized on a scale of zero to one) during various levels of biting pressure from *Leptoconops americanus* during May 4–12, 1993. Numbers at tops of bars are actual mean values of temperature (°C) or wind (kph).

decreased cloud cover, and absence of rain all favored higher biting rates.

Absence of biting was associated with the highest frequencies of clouds and rain, the lowest frequency of full sun, the lowest mean temperature, and the highest mean wind speed (Figs. 1 and 2). At low biting rates (1–29 bites per 15 min), the mean temperature (17°C) was within the favorable range, but mean wind speed was high (4.7 kph), and cloudiness and lack of sun were frequent. It was difficult to determine weather conditions that were associated with the difference between moderate (30–59 bites per 15 min) and high (60–89 bites) biting rates. Conditions were generally favorable, though there was a higher frequency of intermittent sun during moderate biting and a high mean wind speed during high biting rates. The highest biting rates (>90 bites per 15 min) occurred when all measured weather conditions were favorable (i.e., temperatures above 15°C, the lowest mean wind speeds observed, complete lack of clouds, sun exposed during each observation, and no rain).

Analysis of mean ranks of observations and of the number of observations above or below the median (Table 1) suggested that biting rates from 1400 to 2000 h were greater than during other periods. These analyses do not correspond to simple mean biting rates, which were greatest from 0700 to 0800 and from 2000 to 2100 h. This discrepancy suggests that outlying values distorted the means.

The diel pattern of biting was also examined by graphing biting rates on days with generally unfavorable conditions (May 4–9) and observations of biting rates on individual days when conditions were generally favorable (May 10, 11, and 12) (Fig. 3). During unfavorable days, the mean temperature reached 12°C at noon and never passed 15°C for the rest of the day. After noon, the mean biting rates increased when the

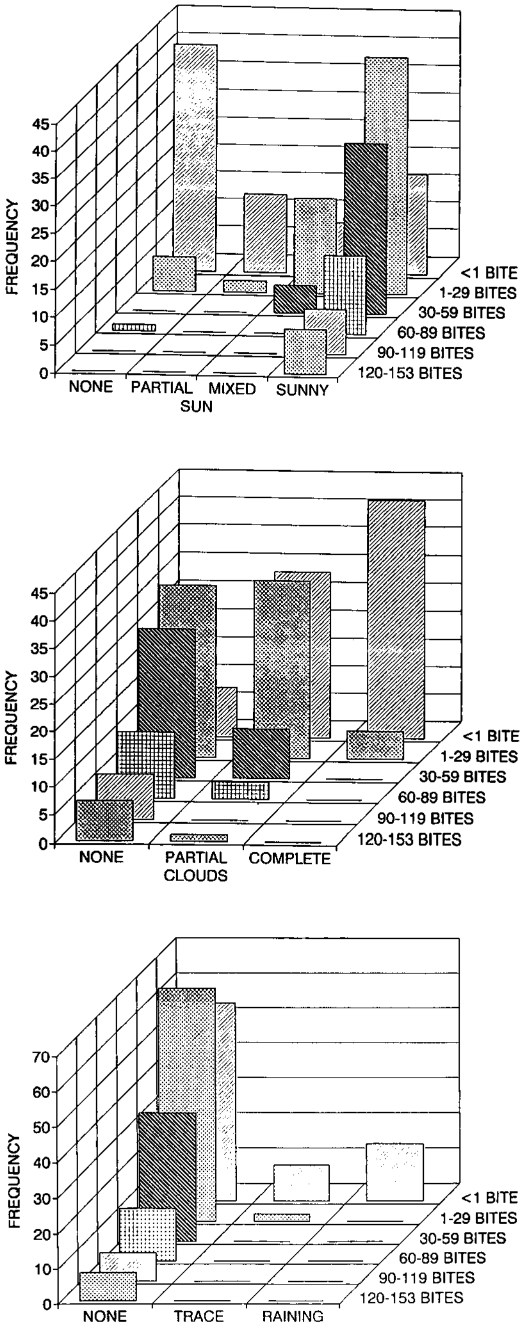

Fig. 2. Frequency distributions of categories of cloudiness, sun, and rain during various levels of biting pressure from *Leptoconops americanus* during May 4–12, 1993.

mean wind was under 5 kph from 1430 to 1830 h. On May 10, the biting rate increased when the temperature reached 15°C at 1100 h, then the biting rate followed no particular pattern, remaining at a moderate to high level. On May 11, the day started with the temperature above 15°C and the biting rate was highest in the earliest collections, from 0800 to 1100 h. Finally, May 12 was warm in the morning when the highest biting rates were observed. Wind increased in the afternoon and biting rates declined until there was less wind at 1700 h. Biting then increased, forming a secondary peak of activity from 1700 to the end of the day.

DISCUSSION

Some studies of *Leptoconops* have reported a biphasic pattern of diel activity. Biting of *L. spinosifrons* in the Philippines was observed during 2 days with maximum biting from 0700 to 0900 and from 1600 to 1800 h when temperatures were below 28–30°C (Takaoka et al. 1976). *Leptoconops nipponensis* also bit in greatest numbers in the morning and late afternoon when temperatures were between 21 and 25°C during a single day of collections (Matayoshi et al. 1985). Using carbon dioxide-baited traps for one day, Brenner et al. (1984b) observed greatest activity of *L. knowltoni* in California at sunrise and again from 1330 h to sunset. Wind was absent in the morning and strong in the afternoon; peak biting activity occurred at 32 and 38°C. The afternoon peak corresponded to a greater number of parous females (Brenner et al. 1984a).

Some other species of *Leptoconops* have displayed no particular pattern of diel activity, responding to prevailing weather conditions. Whitsel and Schoeppner (1966) claimed that *L. carteri* in California was attracted to carbon dioxide-baited traps in greatest numbers when the wind was less than 8 kph and the temperature was between 25 and 35°C. In a thorough analysis of three days' biting collections in French Polynesia, Aussel (1993) concluded that *L. albiventris* was most abundant in bright sun, at higher temperatures (29.5–31.3°C), and low wind.

The results of our study, conducted during 9 days, suggested that biting activity of *L. americanus* does not follow a particular diel pattern. Apparent diel patterns were evidently the result of conditions prevailing at the time, as we observed peak biting in the morning, mid-afternoon, or late afternoon depending on the weather. The greatest biting rates of *L. americanus* occurred when temperatures were above 15°C, wind was absent, and the sun was exposed. Rain and low temperatures (< 10°C) acted as threshold conditions, eliminating biting activity. Cloudi-

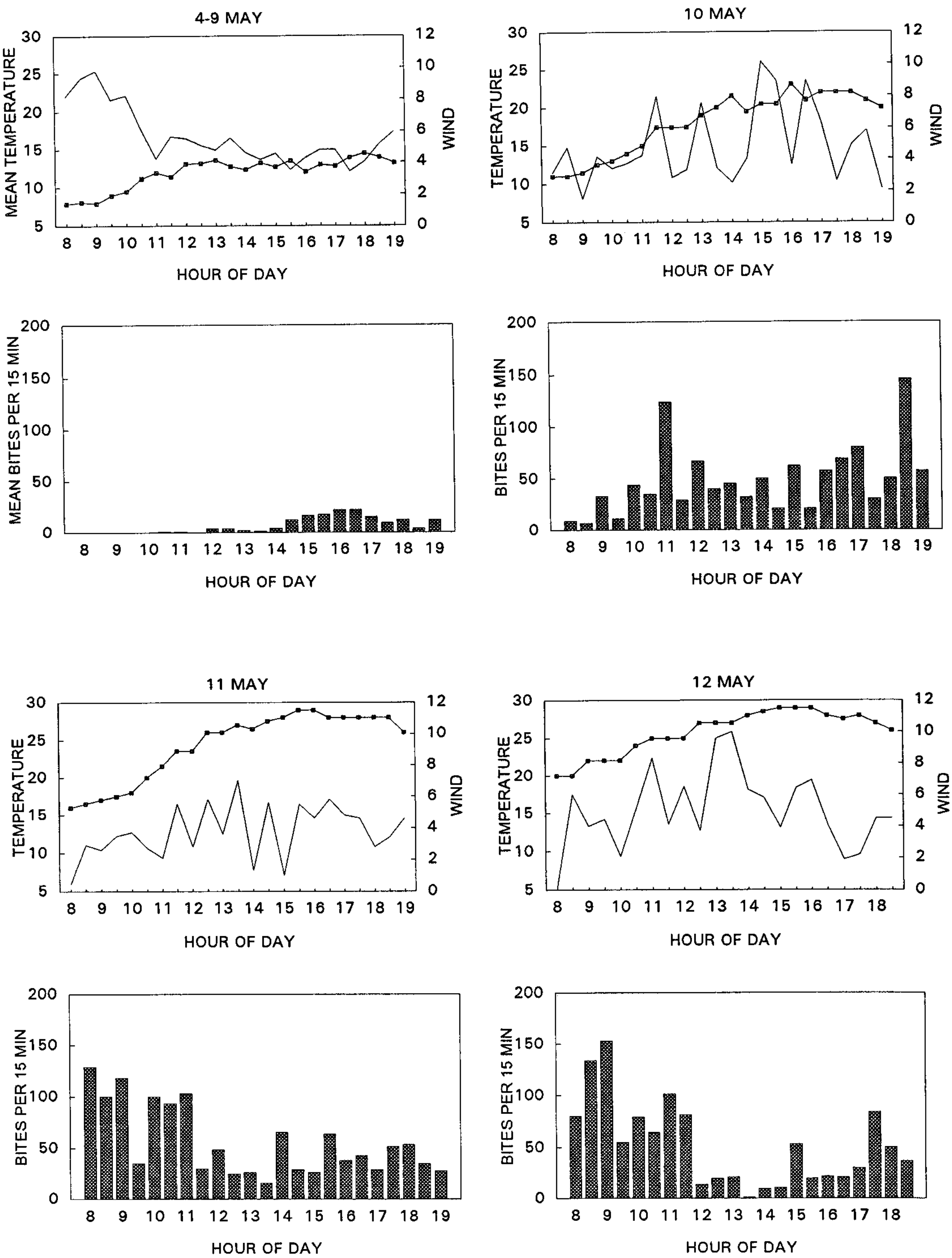

Fig. 3. Half-hourly records of mean temperature (bold line, with squares), wind (solid line), and biting rate of *Leptoconops americanus* during generally unfavorable conditions on 6 days (May 4–9) and during generally favorable conditions on each of 3 days (May 10–12).

ness and higher winds (>5 kph) reduced biting when conditions were otherwise favorable. *Leptoconops foulki* and *L. knowltoni,* in contrast to *L. americanus,* were most active in strong winds of 8–16 kph (Brenner et al. 1984a). *Leptoconops americanus* appears to share a preference for bright sunlight and low winds with *L. carteri* and *L. albiventris,* but *L. americanus* was active at lower temperatures. Although not statistically significant, there was some suggestion in our data (Table 1) that biting was reduced at the highest temperatures (25–29°C) observed. Further sampling as seasonal temperatures increased might have confirmed the negative effect of higher temperatures; Tooele Valley vector control personnel generally consider the biting midge season to end when temperatures exceed 32°C (Walt Brandt, personal communication).

Familiarity with the biting habits of *L. americanus* can be used to avoid disruption of outdoor activities in areas where this species is abundant. When possible, activities can be conducted during cool, cloudy, windy weather. During weather when biting conditions are favorable, liberal use of repellents and protective clothing can offer considerable relief.

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