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EFFECT OF WIND VELOCITY ON SUCTION TRAP CATCHES OF SOME FLORIDA MOSQUITOES

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ABSTRACT. The correlations between wind velocity and suction trap catches of mosquitoes when taken at 15-min intervals during the night were studied at 2 locations. Although normal mosquito flight speeds are approximately 1 m/sec, trap catches were reduced about 50% by winds of 0.5 m/sec and 75% at 1.0 m/sec. Trap catches were inversely related to winds of all velocities and even the lightest winds reduced trap catches. No evidence was found for a threshold below which wind velocity had no effect.

INTRODUCTION

The effects of weather are major factors in attraction and capture of adult mosquitoes. In contrast to absolute samples, which determine number of individuals occupying a unit of habitat (Southwood 1977, Service 1993), most surveillance techniques provide relative samples because both the dimensions of the area being sampled and efficiency of the sampling method are poorly known. Physical characteristics of the trap site and efficiency of sampling techniques change slowly with time whereas weather may change rapidly. How well a relative sample represents the existing mosquito population will be affected by inhibiting levels of illumination, temperature, humidity, and wind velocity (Klassen 1968, Service 1978). Several studies have reported wind velocities above which catches were reduced (Gjullin et al. 1961; Bailey et al. 1965; Snow 1976, 1980; Gorman 1979; Service 1980). Arctic mosquitoes excepted, these threshold velocities ranged from 0.8 to 2.1 (mean = 1.2 m/sec). Bidlingmayer (1985) reported that, over a range of velocities, catches of *Culex nigripalpus* Theobald were reduced 8–12% by each increase of 0.1 m/sec in wind velocity. The objective here was to determine the effect of differing wind velocities upon trap catches of mosquitoes.

MATERIALS AND METHODS

This study was conducted in 2 areas along the east coast of Indian River County, FL, during the summers and autumns of 1983–85. To meet the objectives of the study, sampling criteria were established to reduce effects of different levels of illumination, temperature, and humidity upon trap catches.

Illumination: Between sunset and sunrise the principal sources of illumination are refracted light from the sun and moonlight. During this time, an important factor determining the proportion of the mosquito population in flight is illumination level (Bidlingmayer 1974). In Florida, truck trap collections showed mosquito flight activity was greatest during the twilight periods that follow sunset and precede sunrise. In addition, lunar illumination at any time during the night would also stimulate increased flight activity.

To avoid effects of changing levels of solar illumination upon mosquito flight activity, the first nightly suction trap collection began just after 2.8 crep, a crep being defined as multiples of civil twilight (Nielsen 1963). Subsequent collections during the night were considered valid only when the moon was either always present or always absent. The last collection was completed 6.5 h later, before the corresponding increase in illumination preceding sunrise. Because all collections during the night were taken at essentially the same illumination level, the effect of between-night differences in lunar illumination upon catches would be included within between-night population differences.

Temperature and humidity: Florida summers are warm and humid with most rainfall provided by thunderstorms. Temperatures and relative humidities were recorded at the 2 study areas by a hygrothermograph placed in a standard instrument shelter. Temperatures as low as 19–21°C did not reveal any inhibition in the level of mosquito flight activity whereas at 18°C catches were reduced about 25% (Bidlingmayer 1985). Trap data in our study were discarded whenever temperatures were <18°C.

The influence of relative humidity upon mosquito flight is poorly understood. For *Cx. nigripalpus,* flight activity during the night increased about 3.5% (Dow and Gerrish 1970) to 5% (Bidlingmayer 1974) for each 1% increase in humidity above the average evening humidity. Trap catches in our study were not screened for the effect of relative humidity.

Wind measurements: Wind velocities were measured with Model 106 sensitive cup anemometers (C. W. Thornwait Associates, Elmer, NJ) that had transparent cups and a starting threshold speed of 0.115 m/sec with an upper limit of 14.5 m/sec. Anemometer contacts were accumulated on separate registers and recorded at 15-min intervals by a Model 706 DC digital recorder (C. W. Thornwait Associates). These readings were subsequently converted into a mean wind velocity for each 15-min collection.

Study Area I: This area was located on a low peninsula that projected eastward into the salt marsh 10 km south of Vero Beach, FL, at the Florida Medical Entomology Laboratory. The site measured about 45 × 30 m and was slightly above tidal levels. The surface was partially bare earth with the remainder covered by salt-tolerant grasses about 15–25 cm in height. On the marine side was a border of mangroves and salt-tolerant shrubs about 3–4 m in height. The base of the peninsula adjoined an area of small live oaks with a shrubby understory.

Plywood suction traps (Bidlingmayer 1974) were modified by removing the elevated air intake. Traps measured 2.4 × 0.8 × 0.8 m with an 0.8 × 0.8-m opening at one end of the upper surface to serve as the air intake. Traps were equipped with a 61.0 cm exhaust fan powered by a 220-V ½-hp electric motor that enabled the fan to sample about 120 m^3 of air per minute. Air was drawn downward, passed through a vertical screen cone, turned 90°, passed through the fan, and discharged horizontally, The apex of the cone was fitted with an automatic collection cup changer (Bidlingmayer and Evans 1985) that provided 26 collections each night.

To insure synchrony between mosquito catches and anemometer readings, the cup changer was also controlled by the digital recorder. Therefore each wind record was paired with a 15-min trap catch. A relay-operated pen arm attached to the hygrothermograph recorded any power failures during the night.

Four suction traps were placed in a north–south row beneath a wooden frame constructed in the shape of a truncated rectangular pyramid. The pyramid measured 27.4 × 10.1 m at its base and 23.8 × 6.4 m at the upper surface. The vertical height was 1.14 m and the sides sloped downward and outward at an angle of about 32°. The upper surfaces of the traps were elevated to the same height as the pyramid with the trap intakes spaced equidistantly along its midline. The top and sides of the wooden frame were covered with burlap fabric except over trap intakes and consequently the traps were not visible to mosquitoes. Only the upper ¾ of the 2 ends were covered with burlap, as an opening was necessary for the fan exhausts to escape. The sloping sides of the pyramid enabled low-flying mosquitoes to continue their flight without interruption.

An anemometer supported by an offset metal rod was centered directly above each trap's air intake at an elevation of 1.0 m. Anemometers placed at elevations lower than 1 m above the intake had shown greater velocities than at 1 m, indicating they were affected by the torque of the downdraft caused by the fan. Therefore, 2 additional anemometers were placed midway between the 2 center traps. These were erected at elevations of 20 cm and 1 m above the burlap. Data provided by the anemometer at 20 cm consistently showed lower wind velocities than the anemometer at 1 m. From these data correction factors, which varied with wind velocity, were calculated to provide estimates of wind velocities at 20 cm above each trap's intake. These estimated values were used to represent true wind velocities for each trap.

Visual attractancy to the burlap-covered frame from a distance by mosquitoes is probable (Bidlingmayer 1994). Every trap environment differs to some degree from all others and mosquito densities above trap intakes may also differ. However, as the trap catch and wind record were taken at the same spot, differing densities among traps were no different than differing densities among nights. Collections were not pooled to average differences among trap catches.

Study Area II: This site was an inland location 12 km northwest of Vero Beach, FL. The surrounding area consisted of pastures and swamps with some xeric scrublands. The scrublands were old sand dunes covered by dense woody vegetation about 2 m in height. The trap site was located in a clearing (approximately 3 × 8 m) in the scrub.

A single suction trap was used at this site and it was not covered with burlap. Therefore, it was assumed to be both visually attractive and to serve as a windbreak (Bidlingmayer 1985). The trap's horizontal dimension was lengthened by 1.5 m to more widely separate entering and discharging air streams. To minimize the effect of fan exhaust upon low-level winds, after indrawn air had passed through the fan it was again turned 90° and discharged upward. An anemometer was placed 1 m above the trap intake and wind data corrected as at Area I to provide estimates of wind velocities at 20 cm above the intake. Trap collections and wind records were taken at 15-min intervals.

Data analysis: For reasons including power and equipment failures, low temperatures, or the occurrence of moonrise or moonset during the night, the full number of 26 collections each night was not always available. Nights with fewer than 15 sequential collection periods were discarded. Wind velocities recorded for each period were grouped by increments of 0.10 m/sec (*viz.*, 0.11–0.20, 0.21–0.30, . . . , m/sec, with midpoint values of 0.15, 0.25, . . . , m/sec). Velocities < 0.11 m/sec were not recorded. We assumed that the size of mosquito populations did not change appreciably during a 6.5-h test period. Data from each night were first tested to determine correlation coefficients (r) between wind velocities and trap catches. Because each collection was only of 15-min duration, many collections during a night were negative. After analyzing the data to identify the threshold for significant correlations ($P < 0.10$), we determined that catches should be discarded if a combined night's catch averaged <0.8 female mosquitoes per collection. The rationale for the selection of $P < 0.10$ as a threshold for significance will be postponed.

In addition to nights with mean catches of <0.8 females per collection, there were other possible causes for nonsignificant collection vs. windspeed interactions. To illustrate, assume the wind during a night was steady. Because r is a measure of the relationship between 2 variables, the wind velocity/trap catch correlation would not be significant if wind velocities had been steady. As nightly wind velocities become more variable and/or mosquito populations larger, the probability of obtaining significant correlations should increase. Assuming that the physical effect of a particular velocity upon mosquito flight during the night should not differ whether the night's winds proved to be steady or variable, nights with significant and nonsignificant correlations were analyzed separately.

Further preliminary analyses were necessary for the following reasons. 1) Because mosquito populations change over time, catch variances were not independent of their means. Therefore, each catch was transformed into the logarithm of $x + 1$. 2) The number of wind records representing very low and very high wind velocities were too few to enable the means ($\log_{x+1}$) of their associated catches to be centrally located. The minimum number of wind records necessary to provide a centrally located mean catch for each velocity group varied with species and ranged from 85 to 147. Wind groups containing a smaller number of records were merged with an adjacent group to create a larger group with weighted means for both velocity and catch.

Transformed ($\log_{x+1}$) mosquito collections made during significant and nonsignificant nights were compared by linear regression (SYSTAT, Evanston, IL) with the wind speeds recorded during the collection periods. The transformed data were also examined with curvilinear regression analysis (SYSTAT) by fitting the mean number of mosquitoes captured vs. the mean wind speed for the collection to quadratic ($Y_{est} = a + bx + cx^2$) and logarithmic ($Y_{est} = a + b_{\log}[x]$) equations. The resulting r^2 values were used to determine the best fit for the data.

RESULTS AND DISCUSSION

The major mosquito species captured in our study, in order of abundance, were *Deinocerites cancer* Theobald, *Cx. nigripalpus, Aedes taeniorhynchus* (Wied.), and *Anopheles crucians* (Wied.). Trap catches of species taken in num-

Table 1. Number of trap nights when correlation coefficients (r) between the night's wind velocities and mosquito collections were significant ($P < 0.10$) or nonsignificant ($P > 0.10$).

	No. trap nights[1] with r negative				No. trap nights[1] with r positive				
Species	$P <$ 0.01	$P <$ 0.05	$P <$ 0.10	$P >$ 0.10[2]	$P >$ 0.10[2]	$P <$ 0.10	$P <$ 0.05	$P <$ 0.01	Total
Area I									
De. cancer	121	55	37	99	46	0	3	0	361
Cx. nigripalpus	131	45	16	95	33	1	1	0	322
Other species[3]	54	40	18	116	49	4	3	0	284
Ae. taeniorhynchus	5	12	6	34	11	1	1	1	71
Area II									
Cx. nigripalpus	30	15	14	46	19	1	2	0	127
Other species[3]	19	19	5	53	25	1	1	0	123
An. crucians	2	3	5	18	7	2	2	0	39
Total	362	189	101	461	190	10	13	1	1,327

[1] The number of collections taken during a trap night varied from 15 to 26.

[2] P = Nonsignificant.

[3] Consolidated catches (whenever a night's catch of any one species averaged < 0.8 mosquitoes per collection).

Table 2. The number of trap collections taken on nights when each night's correlation coefficients between wind velocity and trap catches were either significant ($P < 0.10$) or nonsignificant. Also shown are the percentage of these collections found in the 4 largest contiguous wind velocity groups.

		Area I			Area II		
Species	Corr. coef.[1]	No. of collections	Wind velocity (m/sec)	%	No. of collections	Wind velocity (m/sec)	%
De. cancer	S	5,174	0.45–0.75	40	—	—	
	NS	3,705	0.35–0.65	68	—	—	
Cx. nigripalpus	S	4,309	0.45–0.75	42	1,503	0.35–0.65	55
	NS	2,761	0.35–0.65	72	1,619	0.25–0.55	70
Other species[2]	S	2,903	0.45–0.75	40	987	0.35–0.65	51
	NS	3,838	0.35–0.65	72	1,468	0.25–0.55	75
Ae. taeniorhynchus[3]		1,579	0.45–0.75	59	—	—	—
An. crucians[3]		—	—		701	0.25–0.55	56

[1] S = significant; NS = nonsignificant.

[2] Consolidated catches (whenever a night's catch of any one species averaged < 0.8 mosquitoes per collection).

[3] Trap nights with significant and nonsignificant correlation coefficients were combined.

bers too small for separate analysis were combined to provide a sample ≥0.8 mosquitoes per collection and subsequently analyzed in the Other Species category. At Area I, the low-collection species included, in descending order, *Anopheles atropos* Dyar and Knab, *Culex* (*Melanoconion*) spp., *Coquillettidia perturbans* (Walker), *Psorophora columbiae* (Dyar and Knab), and *Aedes infirmatus* Dyar and Knab. At Area II, low-collection species included *Ps. co-*

Table 3. Estimated mean numbers (antilog x − 1) of female mosquitoes captured per collection at a wind velocity of 0.25 m/sec. Estimated mean numbers of mosquitoes captured at higher wind velocities are shown as the percentage reduction when the catch at 0.25 m/sec = 100%.

Wind velocity (m/sec)	*De. cancer*		*Cx. nigripalpus*				Other species	
	Area I		Area I		Area II		Area I	
	Estimated mean numbers captured							
0.25	12.8[1]	7.3[2]	15.0[1]	5.8[2]	18.9[1]	13.1[2]	2.9[1]	1.5[2]
	Percent reduction							
0.33	25	14	30	21	24	9	16	6
0.50	51	31	60	45	50	22	37	15
0.67	65	42	74	58	63	29	49	21
0.75	69	45	78	63	67	32	54	23
1.00	78	54	86	73	76	39	64	29
1.25	84	60	91	79	81	44	71	33
1.50	88	64	94	84	85	47	76	36
1.75	90	67	96	87	88	50	80	39
2.00	92	70	98	90	90	53	83	41
2.25	94	73	99	92	91	55	86	43
2.50	95	74	100	94	93	56	88	45
2.75	96	76	101	95	94	58	90	46
3.00	97	78	101	97	95	59	92	48
Adjusted r^2[4]	0.91***	0.81***	0.94***	0.95***	0.97***	0.07^{NS}	0.97***	0.65***

[1] Significant nights.

[2] Nonsignificant nights.

[3] Significant and nonsignificant nights combined.

[4] * $P < 0.05$, ** $P < 0.02$, *** $P < 0.01$, NS = nonsignificant.

lumbiae, Culex erraticus (Dyar and Knab), *Aedes vexans* (Meigen), *Culiseta melanura* (Coq.), and *Anopheles quadrimaculatus* Say.

Records for 122 nights in Area I showed mean (±1 SD) maximum and minimum temperatures were 25.5 ± 2.8°C and 24.1 ± 1.9°C, respectively. Mean maximum and minimum mean temperatures for 128 nights in Area II were 26.1 ± 2.4°C and 24.1 ± 2.5°C, respectively. Maximum and minimum mean relative humidities for 116 nights in Area I were 90 ± 5% and 83 ± 7%; for 129 nights in Area II these were 95 ± 3% and 88 ± 5%, respectively. Because the night's trapping did not begin until well after twilight, after the most rapid changes occurred, and did not exceed 6.5 h, differences between maximum and minimum readings were small.

Table 1 shows the number of trap nights for the more common species grouped according to whether correlation coefficients between each night's wind velocities and its catches were significant or nonsignificant. Trap nights with positive correlation coefficients comprised <2% of all nights and were discarded from further study. The remaining trap nights appeared to comprise 2 well-defined groups, one negatively significant ($P < 0.10$) and the other nonsignificant. Within the latter group a preponderance of trap nights had negative values of r. The number of significant and nonsignificant trap nights to be analyzed was almost equal.

Table 3. Extended.

Other species		*Ae. taeniorhynchus*	*An. crucians*
Area II		Area I	Area II
Estimated mean numbers captured			
2.8[1]	1.8[2]	1.4[3]	1.7[3]
Percent reduction			
18	9	11	18
41	22	25	41
55	30	35	56
59	33	38	61
70	41	47	72
77	46	53	80
83	50	58	86
87	54	62	91
90	57	65	95
93	59	68	98
95	61	70	101
97	63	73	103
99	65	75	105
0.88***	0.75***	0.54**	0.99*

A major difference between wind velocity patterns of significant and nonsignificant nights is shown in Table 2. For *De. cancer,* 40% of all catches made on nights with significant wind velocity/catch correlations were taken within the range of 0.45–0.75 m/sec; on nonsignificant nights 68% were taken within a range of 0.35–0.65 m/sec. Nights with significant correlation coefficients had both stronger and more variable winds than nonsignificant nights. Other species in this table showed the same pattern.

A logarithmic regression provided the best fit between wind velocities and catches for all species. The regression equations obtained for each species were used to calculate an estimated mean catch per collection at arbitrarily selected wind velocities. Table 3 shows estimated mean catches taken for the smallest velocity class (i.e., 0.25 m/sec). Catches taken at this velocity are assumed to represent the maximum possible catch (i.e., 100%). Estimated mean catches for higher wind velocities are shown as the percentage reduction from that catch. The principal findings and conclusions were:

1. Trap catches declined as wind velocities increased over the entire range of observed velocities. Wind velocities within the range of normal mosquito flight speeds, about 1 m/sec, resulted in trap catch reductions on significant nights of approximately 50% by winds of 0.5 m/sec and 75% at 1.0 m/sec. There was no evidence of a velocity threshold below which catches would become equal. It appears that, had mean velocities <0.25 m/sec occurred, even larger catches were probable. In this study all nights were windy and no nights were calm.

2. The rate of catch reduction with increasing wind velocities was greater on significant nights than on nonsignificant nights. In addition to winds on nonsignificant nights being less variable and of lower velocities (*cf.* Table 2), Table 3 shows that mosquito catches on these nights were also smaller, indicating smaller field populations were being sampled. A wind velocity/trap catch regression based on catches made on significant nights should be more reliable than one based on nonsignificant nights. However, all regression will be affected by, in addition to actual wind velocities experienced, the velocity patterns and mosquito population levels that chanced to occur during the study period. Because optimal experimental conditions are infrequent, the regressions obtained here, even for

significant nights, are probably conservative estimates of the effect of wind upon trap catches.

3. The regression equation for *Cx. nigripalpus* in Area II on nonsignificant nights was not significant (Adjusted $r^2 = 0.07$). It was calculated from wind velocities of 0.23, 0.35, 0.45, 0.55, 0.65, 0.78, and 1.17 m/sec and mean catches (antilog $x - 1$) of 9.2, 12.4, 9.2, 12.6, 12.3, 11.9, and 4.0 females, respectively, per collection. An explanation for this unusual catch pattern is not known, although it is suggestive of a velocity threshold.

4. In contrast to Area I, the trap in Area II was expected to provide mosquitoes with both a visual target and a windbreak. Nevertheless, no apparent differences between areas were found, as the percentage reduction of trap catches for *Cx. nigripalpus* was greater in Area I than in II, and in Area II than I for Other Species. At Area II, the location of the trap within a small clearing in the scrub may have precluded the operation of long range visual responses or the creation of a windbreak.

5. Correlation coefficients between wind velocity and trap catches for individual nights ranged, although strongly skewed, from negative to positive (Table 1). Nights with small values of *r* would be nonsignificant. To separate nights whose catches had been affected by the wind from those that seemingly had not, it seemed prudent to include as significant those nights with a 90% chance (i.e., 0.10) of having catches affected by the wind. This level of significance was used only in the data organization phase of the study.

The inclusion of nights with marginal values of *r* ($P < 0.10$) among those nights with greater *r* values would cause a flatter regression slope for significant nights; the separation of these nights from those nights with smaller values of *r* would also cause a flatter regression slope for nonsignificant nights. Use of $P < 0.10$ during the data organization phase improved the stringency of this analysis. In addition to wind patterns and populations sizes, the criteria for significance will affect regression slopes.

Several mechanisms that may have produced these results were considered:

1. An optomotor anemotactic response permits mosquitoes to fly an upwind flight path (Kennedy 1940). A flying mosquito perceives the ground as a flickering pattern of alternating lighter and darker areas. The mosquito's flight elevation is determined by coarseness of the ground pattern and wind velocity being experienced. Whenever strong winds cause the flicker rate to fall below an acceptable frequency, mosquitoes will either reduce their flight elevation to seek a lower headwind or turn and fly downwind—either response increases the flicker rate.

Taylor (1974) proposed the concept of a boundary layer, the layer of air closest to the ground and whose depth is inversely related to wind velocity. Within the boundary layer, wind velocities are less than an insect's flight speed, permitting upwind flights. Following an encounter with a high wind, mosquitoes that had responded to the reduced flicker rate by reducing their flight elevation would have also increased the aerial density of mosquitoes within the boundary layer. Traps within the boundary layer would then be expected to take larger catches with increasing wind velocities until the traps' elevation exceeded that of the boundary layer. As the wind velocity/catch relationship in this study was inconsistent with this pattern, changes in flight elevation seem to have been of little importance.

2. The wind's effect on trap caches may be direct; low-velocity headwinds would permit greater forward ground speeds and therefore a more rapid rate of arrival at the trap site. As was found in our study, the result should be a continuous inverse gradient between wind velocities and catches.

3. In Indian River County, Day and Van Handel (1986) found flight energy reserves of field-collected females of *Cx. nigripalpus* and *Cq. perturbans,* although variable during the year, averaged about 0.05–0.07 mg/mosquito. As flying females of *Ae. taeniorhynchus* and *Aedes sollicitans* (Walker) consumed about 0.06–0.08 calories/h (= 0.015–0.020 mg) (Nayar and Van Handel 1971), and considering the inability of females to completely exhaust their reserves, the reserves reported by Day and Van Handel would permit approximately 3 h of flight. Therefore, much of the night would be spent resting. The greatest wind velocities tolerated by females before beginning or ending a flight may be related to their energy reserves. To husband their reserves, flight by female mosquitoes with low energy reserves may be performed only at times of low wind velocity, as lower head winds would permit greater distances to be flown. The lower the headwind, the larger the proportion of the population that could be in flight. Complementing the preceding suggestion, such a relationship between energy reserves and flight activity could also produce a continuous inverse gradient between wind velocities and trap catches.

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