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INFLUENCE OF WEATHER ON CAPTURE OF ADULT SOUTHERN POTATO WIREWORM IN BLACKLIGHT TRAPS

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INFLUENCE OF WEATHER ON CAPTURE OF ADULT SOUTHERN POTATO WIREWORM IN BLACKLIGHT TRAPS

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SUMMARY

A survey-type blacklight (BL) trap was operated continuously from April 1956 to December 1967. Seasonal and daily variations in weather (especially fluctuations in temperature) strongly affected the capture of adult southern potato wireworm (*Conoderus falli* Lane). In general, atmospheric conditions became increasingly favorable for capture during April and May, continued highly favorable until mid-September, and thereafter became progressively less favorable through October. However, daily weather conditions stimulated or inhibited capture throughout the year. Temperature thresholds for capture were determined, but these were affected by wind velocity. In general, as temperature increased, beetles could tolerate greater wind velocities without the probability of capture being depressed. Capture was also depressed slightly by relative humidities below 60 percent. Barometric pressure and wind direction did not affect capture.

About 5 percent of the nights during June through September of 1961 and 1962 were conducive to migratory flight activity. On those nights, dramatic increases in catch were recorded. Less spectacular increases in catch were associated with sharp increases in temperature. Reduced catches on subsequent nights probably occurred primarily as the result of trivial flights by individual beetles that previously had been attracted by the BL but had escaped capture by the trap.

Efficiency of the trap was estimated to range between 33 and 88 percent. It appeared that trap efficiency increased as wind velocity increased from 4 to 10 miles per hour.

INTRODUCTION

The efficacy of 15-W blacklight (BL) traps for control of southern potato wireworm (*Conoderus falli* Lane) has been studied intensively at the Vegetable Insects Laboratory, Charleston, S.C., since 1956. Beetles have been attracted to BL traps in great numbers during all months of the year (*1, 2*).[1] An attempt to reduce infestations in an isolated agricultural area to a noneconomical level through 4 years of intensive trapping was not successful (*3*). Concurrent studies indicated that the intensity of trapping (1.1 traps/acre) had been grossly inadequate, primarily because the beetles are strongly attracted only within 17 to 23 ft of the BL bulb (*6*). The light trap project was subsequently terminated because of low feasibility with present technology. This paper attempts to consolidate all related unpublished information and further elucidate the potential role of BL traps in controlling southern potato wireworms. Nearly all data herein are observational in nature. The conclusions are, therefore, based almost exclusively on circumstantial evidence. I believe, however, that credibility is provided by the complementary nature of closely related conclusions.

ACQUISITION AND TREATMENT OF DATA

A survey-type trap, which conformed to Entomological Society of America standards (*4*), was operated continuously with a 15-W BL bulb for the 12-year period, 1956 through 1967, on the same site on the Clemson University Truck Experiment Station at Charleston, S.C. The trap was serviced Monday through Friday at 8 to 9 a.m., except during 1960–61 when it was serviced daily. The number of captured beetles was recorded for each trapping period. Concurrently, minimum, maximum, and 8 p.m. air temperatures were recorded, and precipitation was measured at about 8:30 a.m. each day at a site about 100 ft from the trap. Data on barometric pressure, wind direction, wind velocity, and relative humidity (RH) at 8 p.m. of each day were available from U.S. Weather Service records for a site about 7.5 miles from the trap. These eight weather readings were recorded as representative of each 24-hour period. The data were tabulated and transferred to magnetic tape. Data for all reported analyses were then retrieved

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[1] Italic numbers in parentheses refer to Literature Cited, p. 27.

and tabulated by computer or programmable electronic calculator and were analyzed by calculator.

To avoid "circular" reasoning (that is, fitting a model to data from which it was derived), the data from 1960–61 were usually examined first. If a functional relationship was suggested, the data from 1956–59 and 1962–67 were then analyzed in detail to develop a model. Finally, the model was applied to the 1960–61 data to test its predictive or descriptive value. Because each weather factor tended to require different statistical treatments, these details will be described as individual weather factors are discussed.

EFFECTS OF SEASON AND WEATHER ON BL TRAP CATCH

Seasonal Distribution Of Catch

The total number of beetles captured each month was reported by Day et al. (*2*), but a more detailed analysis was desired. Because only 3-day composite catches were recorded for most of the weekends in the study, weekly totals represented the shortest continuous interval that could be studied for the 12-year period. The seasonal distribution of weekly catch was portrayed by plotting moving averages of weekly catch for the 12-year period (fig. 1). A seven-point moving average was found to remove most minor variation and adequately illustrate seasonal trends.

Most of the major deviations in weekly catch were associated with abrupt changes in prevailing temperature. The observed average temperature for each weekly interval, expressed as a deviation from the 10-year average temperature for the same interval, is also given in figure 1. All temperature averages were calculated as the summation of daily minimum and maximum values divided by 14.

When a population is stable, average catch should tend to rise and fall with average temperature. Therefore, increasing catches associated with constant or decreasing temperatures were considered indicative of increasing populations; the converse was considered indicative of decreasing populations. With the exception of 1966, the data clearly indicate peak catches that represent the two annual generations consisting of a winter brood and a summer brood that normally mature in May or June and August or September, respectively. Also, a conspicuous partial third generation matured in October and November of 1959 and 1961. This life cycle was reported by Day et al. (*2*); it was supported by

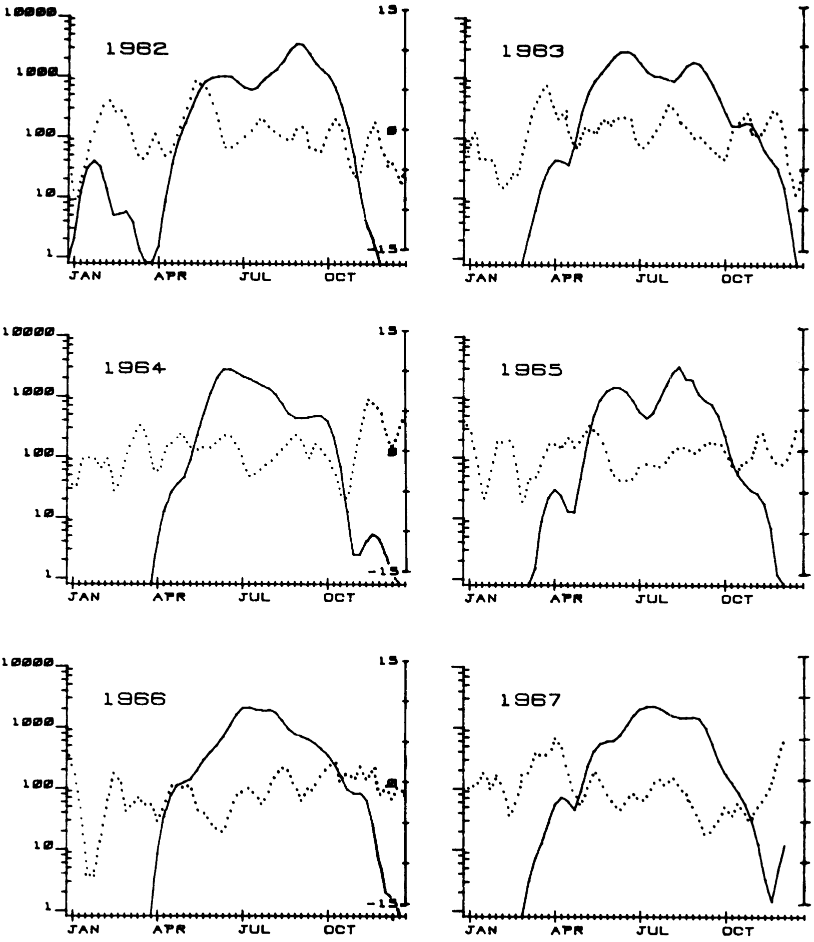
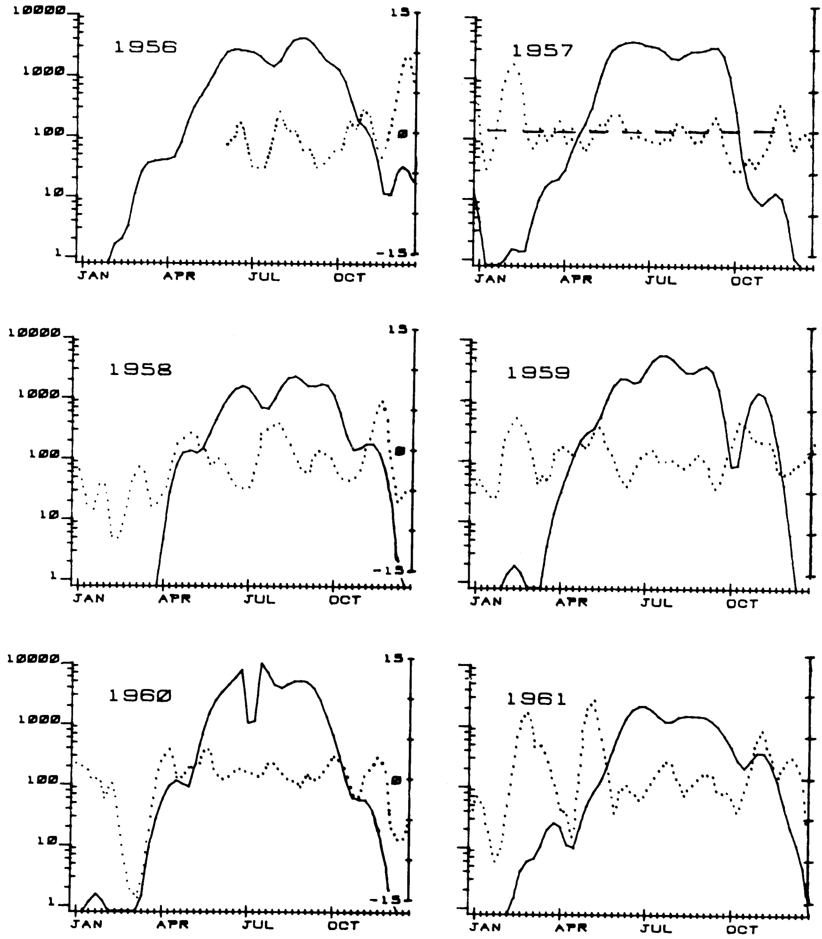


FIGURE 1.—Seven-point moving average of total number of southern potato ordinate) and deviation of observed average weekly temperature from versus 7-day intervals beginning January 1±3 days through December,

their data on occurrence of larvae and pupae, but was not clearly supported by their data on adult abundance.

To depict the relationship between season and the proportion of nights when at least one beetle was captured, days of the year were numbered consecutively from 1 to 365 (366 in 1956, 1960, 1964, and 1968). The data were then tabulated in 7-day intervals, and the proportion of nights per interval during which at least one beetle had been captured was determined. The total number of nights per interval ranged from 44 to 79 (weekends were omitted when beetles had been captured because the night or nights of capture could not be ascertained). Figure 2 gives seven-



wireworm beetles captured per week in a BL trap (solid curve, left the 10-year average temperature for the period (dotted curve, right ordinate) 1956–67.

point moving averages of the proportions converted to percentages; these averages are considered indicative of the average level at which general flight activity occurs throughout the year. Obviously, flight activity is usually nil during December through February, increases rapidly during April and May, occurs nearly every night during July and August, and falls sharply during October. The slight peak in November is undoubtedly due primarily to capture of adults from the periodical second generation of summer larvae that mature during seasons that are warmer than average.

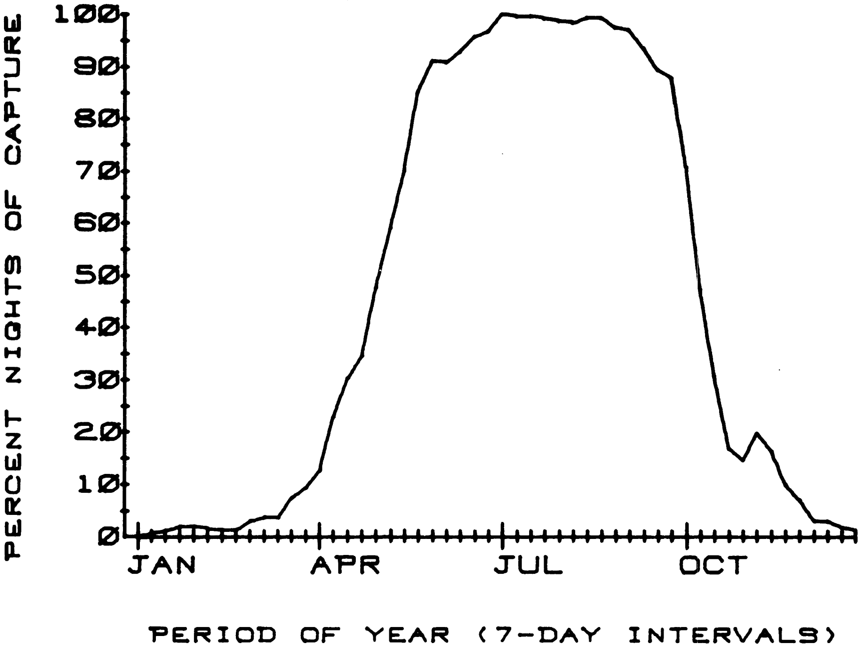


FIGURE 2.—Seven-point moving average of percentage of trap nights when at least one southern potato wireworm beetle was captured as affected by season of the year, 1956–67.

Effects Of Weather On Probability Of Capture

Frequency distributions were prepared for each of eight weather elements under consideration. A total of 3,224 nights were represented, of which 1,277 yielded at least one captured beetle. The range of observed values for each weather element was divided into classes. For each class, a computer tabulated the number of nights when at least one beetle had been captured, the total number of nights of record, and the proportion of catch nights. The proportions were then examined (1) to determine which weather conditions were conducive to flight activity as indicated by the capture of at least one beetle per night, and (2) for evidence of flight thresholds as reported by Taylor (*7*). In all cases, when a frequency class represented a range of observed values, the midpoint of that range was used to represent the class in all subsequent calculations.

Temperature

Much of the seasonal variation illustrated in figure 2 undoubtedly was caused by variation in temperature. I previously stated that three observations of temperature were studied for each 24-hour interval. Maximum daily temperature nearly always occurred during midafternoon preceding each night of record. I included maximum daily temperature in the study on the premise that it may have had a conditioning effect on the beetles. Temperature at 8 p.m. was considered indicative of conditions during the period of maximum flight activity, because Day and Reid (*1*) reported that 69 percent of all captures occurred between sunset and 9 p.m. Minimum temperatures nearly always occurred near sunrise, and were considered indicative of conditions during the late portion of flight activity.

Plots of observed temperature (X axis) versus the percentage of nights during which at least one beetle was captured (Y axis) revealed apparent flight activity thresholds for each of the three temperature factors (fig. 3). For each temperature factor, the data in figure 3 were subjected to probit analysis. An average of 1,063 nights were represented in the data base for each curve. The calculated formulas for the temperature response curves given in figure 3 are as follows:

Minimum temperature: probit $\hat{Y} = -34.48+22.35\ (\log X)$
8 p.m. temperature: probit $\hat{Y} = -61.82+36.72\ (\log X)$
Maximum temperature: probit $\hat{Y} = -61.41+35.18\ (\log X)$

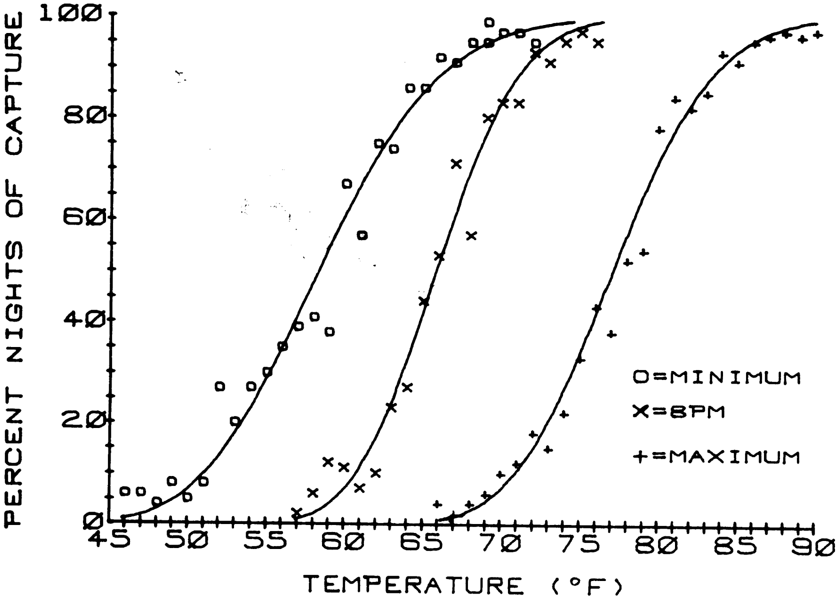


FIGURE 3.—Relationships between daily minimum temperature, maximum temperature, and 8 p.m. temperature, and the percentage of trap nights during which at least 1 beetle was captured, 1956–67.

Capture rarely occurred at temperatures lower than the origins of curves in figure 3; however, zero catches frequently occurred at temperatures higher than the termini of the curves as a result of unfavorable weather factors other than temperature (for example, due to heavy precipitation).

It is clear from examination of the 1- and 99-percent flight activity levels in figure 3 that capture was essentially precluded when minimum temperature, 8 p.m. temperature, or maximum temperature was equal to or less than 46°, 57°, or 66° F, respectively. Likewise, there was little or no inhibitory effect of temperature as such at levels equal to or greater than 74°, 76°, or 90°, respectively. Because temperatures were not associated precisely with the period of capture, the data do not reflect true cause-and-effect relationships. Rather, the given temperatures should be considered as indices of the temperatures that actually influenced flight activity. Because temperature nearly always decreased during the period of capture, and because flight activity is known to be most prevalent during the early evening hours, the observations at 8 p.m. should closely approximate the true relationship. I therefore decided to use the 8 p.m. data in subsequent tabulations to assess the possible influence of other weather factors on flight activity. A further advantage of the 8 p.m. data is that it provided the steepest slope of the three temperature-response curves. This provides the greatest separation of estimated response per unit change in temperature.

Wind Velocity

Preliminary examination of data from 1960 and 1961 suggested that flight activity, as indicated by the proportion of nights during which at least one beetle was captured, was greatly inhibited as wind velocity increased. The remaining data were therefore tabulated to provide contingency tables of flight activity for 2-mile-per-hour intervals of wind velocity between 0 to 19 m/h, inclusive, and for 3° intervals of temperature between 58° and 75° F, inclusive. Chi-square tests indicated no differences in flight activity between wind velocities of 0 to 1 and 2 to 3 m/h, so these classes were combined. Classes for wind velocity of 14 to 19 m/h were also combined because of low individual frequencies. Then, all data based on fewer than 10 observations were omitted. The results are given in table 1.

At temperatures near the lower threshold for flight, flight activity obviously decreased as wind velocity increased. However, as temperature increased, the effect of wind velocity gradually

TABLE 1.—*Observed percentage of nights when one or more beetles were captured, as influenced by temperature and wind velocity at 8 p.m., 1956–59 and 1962–67*

Temperature (°F)	Wind velocity (m/h) 0–3	4–5	6–7	8–9	10–11	12–13	14–19
	Percent						
58–60	9	18	6	3			
61–63	40	20	12	13	0		
64–66	58	51	56	27	20	39	17
67–69	75	88	85	68	54	50	75
70–72	90	92	83	92	87	53	78
73–75	83	89	97	100	90	86	100

decreased to the degree that wind velocity as high as 19 m/h had no measurable effect at temperatures of 73° to 75° F.

Attempts to develop multiple regression or curvilinear regression equations to depict this relationship did not yield accurate or descriptive results, despite the attempted use of probit, logarithmic, and angular transformations. However, it was observed that a modified probit analysis, using observed temperature rather than the log of temperature as the independent (X) variable, gave a reasonably accurate predicted probit of percent nights of capture within each class of wind velocity in table 1. The intercepts and slopes of the predictive equations are given in table 2.

Except for wind velocity data of 12 to 13 m/h, the intercept tended to gradually decrease and the slope tended to gradually

TABLE 2.—*Coefficients in the formula: Probit* $\hat{y} = a + bX$ *where* $\hat{y}$ = *estimated probit of percent nights of capture and* X = *temperature (°F) at 8 p.m.*

Wind velocity (m/h)	Nights in data base	Coefficient a	b
	Number		
0–3	119	−5.382	0.1591
4–5	273	−6.097	.1713
6–7	364	−10.876	.2422
8–9	289	−8.956	.2125
10–11	214	−9.704	.2174
12–13	89	[1]−6.394	[1].1660
14–19	46	−19.155	.3557

[1] Considered aberrant (see text, p. 10).

increase with increasing wind velocity. Therefore, I omitted the data for 12 to 13 m/h as aberrant and applied linear regression techniques to the remaining data to develop formulas for estimating an intercept (a) and slope (b) for any combination of wind velocity and temperature. Regression according to the formulas, $a = -3.007 - 0.8776\ (\text{m/h})$, and $b = 0.1274 + 0.01237\ (\text{m/h})$, accounted for 77 and 84 percent of the total variance among the six acceptable a-values and b-values, respectively, in table 2. Combination of the two formulas yielded the following formula for estimating the probit of expected percent capture (probit $\hat{y}$) as affected by temperature (degrees Fahrenheit) and wind velocity (miles per hour):

$$\text{Probit}\,\hat{y} = [-3.007 - 0.8776(\text{m/h})] + [0.1274 + 0.01237\ (\text{m/h})]\ [°\text{F}]$$

The above formula is rather unwieldy, but poses no problem for use on a computer or programmable calculator. The most serious disadvantage is that the capacity for placing confidence intervals on predicted values was lost early in the maze of mathematical manipulations that finally yielded the formula. To evaluate the accuracy of the formula, estimated probits and their associated percentages of response were compared with observed probits and observed percentages of response. For the data from which the formula was derived (table 1), the sum of squared deviations between 37 observed and predicted values was 14.3 percent and 12.9 percent of the sum of squared deviations between the observed values and their mean for probits and percentages, respectively. This is somewhat analogous to correlation coefficients of 0.926 and 0.933, respectively, with 36 degrees of freedom (df). For the data from 1960–61, the corresponding values for 29 observed and predicted values were 44.2 percent and 31.9 percent, respectively, which is somewhat analogous to correlation coefficients of 0.747 and 0.825, respectively, with 28 df. The formula was, therefore, considered to be accurate enough for this study. For the convenience of the reader, the predicted percentages of capture for a number of temperatures and wind velocities have been tabulated in table 3.

The temperature-wind velocity formula was used extensively to establish frequency or percent response classes in subsequent evaluations of other weather factors. For each day of record, the formula was used to calculate a probit, which was then converted to its percentage or proportion. That value was considered to represent the probability that one or more beetles would be captured during the night in question. For convenience in the

TABLE 3.—*Predicted percentage of capture as influenced by temperature (°F) and wind velocity at 8 p.m.*

Temperature (°F)	Wind velocity (m/h)						
	1.5	4.5	6.5	8.5	10.5	12.5	16.5
	Percent						
50 [1]	2.14	0.25	0.04	0	0	0	0
53 [1]	5.62	1.21	.35	.08	.01	.00	.00
56 [1]	12.53	4.42	1.90	.72	.24	.07	.00
59	23.85	12.42	7.36	4.05	2.06	.97	.17
62	39.24	27.27	20.44	14.75	10.24	6.82	2.67
65	56.55	47.79	41.98	36.35	30.99	26.01	17.44
68	72.67	68.93	66.32	63.63	60.87	58.05	52.31
71	85.10	85.15	85.19	85.23	85.26	85.30	85.37
74	93.04	94.43	95.23	95.94	96.56	97.10	97.96
77 [1]	97.23	98.38	98.90	99.26	99.52	99.69	99.88
80 [1]	99.07	99.64	99.82	99.91	99.96	99.98	99.99

[1] Predictions determined by extrapolation.

remainder of this discussion, any such value will be referred to simply as the "probability of capture."

Wind Direction

Wind direction was reported in the U.S. Weather Service records according to 16 cardinal directions (NNE, NE, ENE, E, etc.). These designations were converted to numerical codes for transfer to magnetic data tape. The computer tabulation and contingency table of observed and expected percent capture as affected by wind direction (table 4) suggested that winds from any northerly bearing were less conducive to capture than wind from southerly directions. It was logical to suspect this to be a response to associated low or high temperatures, respectively, rather than to wind direction alone. Therefore, the programmable calculator was used to prepare a similar tabulation and contingency table that excluded all nights when the probability of capture was less than 10 percent. This process eliminated 47.1 percent of the total nights in the study as unfit for flight on the basis of adverse temperature or wind velocity, or both, but retained 97.4 percent of all nights of capture.

The results (table 4) strongly suggest that wind direction had no effect on capture. Several authors have reached this conclusion by inference, but I am not aware of any other publication in which it is supported by direct data. The logical nature of the conclusion and the fact that an apparent effect of wind direction was completely eliminated by the temperature-wind velocity formula are considered further evidence of the validity of the formula.

TABLE 4.—*Relationship between number of nights of capture and wind direction at 8 p.m., 1956–67*

	Computer tabulation for all nights on record			Calculator tabulation of nights when the probability of capture ≥10 percent		
		Number of catches			Number of catches	
Wind direction	No. of nights	Observed	Expected[1]	No. of nights	Observed	Expected[1]
NNE	219	54	87.8	68	50	50.2
NE	177	61	70.9	82	57	60.5
ENE	162	52	64.9	82	52	60.5
E	166	70	66.5	83	68	61.3
ESE	201	97	80.6	118	96	87.1
SE	168	82	67.3	99	77	73.1
SSE	234	117	93.8	152	113	112.2
S	208	120	83.4	142	119	104.8
SSW	496	272	198.8	356	269	262.8
SW	326	140	130.7	206	139	152.1
WSW	185	82	74.1	109	82	80.5
W	118	31	47.3	41	30	30.3
WNW	148	29	59.3	41	28	30.3
NW	100	9	40.1	16	7	11.8
NNW	93	10	37.3	23	8	17.0
N	120	25	48.1	33	24	24.4
Total	3121	1251	1251	1651	1219	1219
Chi-square			150.24			13.35
p			3.6×10^{-8}			0.575

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[1] Expected catches equals (number of nights in subclass times total number of catches) divided by total number of nights.

Barometric Pressure

The association between atmospheric pressure (as inches of mercury at 48 ft above sea level) and percent capture was tabulated by computer as follows:

Inches Hg pressure	*Total number of nights*	*No. of captures*	*Percentage of captures*
≤29.59	39	6	15.39
29.60—29.69	59	5	8.47
29.70—29.79	135	39	28.89
29.80—29.89	343	146	42.46
29.90—29.99	619	340	54.92
30.00—30.09	795	433	54.46
30.10—30.19	623	240	38.52
30.20—20.29	326	56	17.17
30.30—30.39	189	12	6.35
≥30.40	96	0	0

The percentage of capture obviously decreased as pressure departed from the observed average of 30.01 inches for the 12-year period. This response was considered unlikely to be associated with pressure alone, but rather was probably associated with turbulent weather in general at extremes of barometric pressure. The data were, therefore, retabulated by calculator to obtain contingency tables of capture nights and total nights for each of the 12 years. Within each contingency table, data were cross-classified according to the deviation of observed barometric pressure from the 12-year average versus the probability of capture. For both criteria, classes for grouping data were established in increments of 0.1 originating from zero. In most of the probability classes, the distribution of frequencies was symmetrical above and below mean barometric pressure. The actual deviations were, therefore, converted to their absolute values, and classes were combined accordingly. This process not only affected convenience by reducing the number of classes, but also, of greater importance, it essentially doubled the frequency in each remaining class.

The data were next combined into two "replicates" representing the first 6 years and last 6 years of the study. Data in pressure classes representing deviations of 0.20 to 0.40 inch from average were combined to eliminate low frequencies in some of the subclasses, and all data for pressure deviations greater than 0.40 inch from average were omitted because most subclasses were not represented. The observed percent capture was calculated for each remaining class and transformed to $\arcsin \sqrt{\text{percent}}$, and the data were subjected to a factorial analysis of variance.

There were no significant differences attributable to departure of pressure from average or to interaction between pressure and probability of capture (table 5). While this suggested a lack of direct influence by pressure, above and beyond indirect consequences that were accounted for by the temperature-wind velocity formula, a trend toward reduced capture was evident as pressure departed from average. Moreover, the credence of the analysis was considered questionable because of wide variation in the number of observations from which percentages of response were calculated (the range was 3 to 303). I therefore decided to combine data from all 12 years and subject it to further scrutiny in an attempt to base the evaluation on actual observed frequencies rather than on proportions derived from very low frequencies.

A portion of the combined data pertaining to total nights of record is given in table 6. The obvious lack of independence in

TABLE 5.—*Arcsin $\sqrt{\text{percentage of capture}}$ as affected by probability of capture and by the absolute value of deviation of barometric pressure from the observed mean of 30.01 in 1956–67*

Probability of capture (p)	Deviation of pressure from mean (inches Hg)			
	0–0.10	0.11–0.20	0.21–0.40	Mean
$0 \leq p < 0.10$	8.4	9.4	8.1	8.6
$.10 \leq p < .20$	23.9	22.2	13.3	19.4
$.20 \leq p < .30$	28.8	27.2	17.6	24.5
$.30 \leq p < .40$	43.7	37.4	37.4	39.5
$.40 \leq p < .50$	49.4	42.4	54.2	48.7
$.50 \leq p < .60$	51.2	56.0	38.5	48.6
$.60 \leq p < .70$	56.6	67.0	56.3	60.0
$.70 \leq p < .80$	71.7	68.5	67.5	69.0
$.80 \leq p < .90$	73.2	72.1	57.4	67.5
$.90 \leq p < 1$	79.4	76.6	78.9	78.3
Mean	48.5	47.9	42.9	

TABLE 6.—*Observed and expected (in parentheses) number of nights of record, cross-classified according to probability of capture versus the absolute value of deviation of barometric pressure from the observed mean of 30.01 in 1956–67*

Probability of capture (p)	Deviation of pressure from mean		
	0–0.10	0.11–0.20	0.21–0.40
Comparison 1: Chi-square = 352, $p = 1.4\times^{-6}$			
$0 < p < 0.10$	511 (698)	427 (412)	492 (320)
$.80 \leq p < 1.00$	665 (478)	266 (281)	47 (219)
Comparison 2: Chi-square = 11.89, $p = 0.454$			
$.10 \leq p < .20$	85 (96.4)	68 (61.2)	38 (33.3)
$.20 \leq p < .30$	52 (54.0)	33 (34.3)	22 (18.7)
$.30 \leq p < .40$	43 (42.41)	22 (26.9)	19 (14.6)
$.40 \leq p < .50$	40 (38.4)	24 (24.4)	12 (13.2)
$.50 \leq p < .60$	38 (37.36)	23 (23.7)	13 (12.9)
$.60 \leq p < .70$	49 (46.0)	30 (29.2)	12 (15.87)
$.70 \leq p < .80$	52 (44.4)	28 (28.2)	8 (15.34)

comparison 1 clearly shows that high probabilities of capture (>80 percent) were observed less frequently as pressure departed from average. In other words, effects of temperature, or wind velocity, or both were confounded with effects of barometric pressure in the primary data (the total number of nights of record). Therefore, regarding possible exclusive effects of barometric pressure on the concomitant data (the number of nights when insects were captured), I concluded that meaningful evaluations would be possible only if some portions of the primary data consisted of frequencies that were distributed independently within the cross-classification of weather factors. Fortunately, the majority of the primary data met this requirement.

Comparison 2 provides a slight suggestion of dependency between the probability of capture and departure of pressure from average, because observations in the corners of the tabulation were the primary contributors to the calculated chi-square. However, the observed frequency distribution was well within limits normally expected due to pure chance in spite of complete independence. Therefore, the data base of comparison 2 was accepted as representing an independent distribution of nights when the capture of a beetle was possible. Tests for independence among concomitant data for those nights should, therefore, provide a legitimate test to determine if barometric pressure exerted a direct influence on capture.

The concomitant data are tabulated in table 7. To recapitulate, omission of all nights when the calculated probability of capture was less than 10 percent was justified on the grounds that temperature or wind velocity, or both, precluded capture regardless of barometric pressure. Omission of all nights when the calculated probability of capture was 80 percent or greater was justified on the grounds that influences of temperature, wind velocity, and barometric pressure were confounded in the data base (the distribution of total nights of record). All data for pressure deviations greater than ± 0.40 were omitted because of low frequencies and missing data. Table 7 provides no evidence of dependency among the remaining data. I therefore concluded, without reservation, that barometric pressure had no effect on flight activity

TABLE 7.—*Observed and expected (in parentheses) number of nights when at least one beetle was captured, cross-classified according to probability of capture versus departure of barometric pressure from the observed mean of 30.01 in 1956–67*

Probability of capture (p)	Departure of pressure from mean		
	0–0.10 inch	0.11–0.20 inch	0.20–0.40 inch
		Number of nights	
$0.10 \leq p < 0.20$	12 (12.80)	9 (7.37)	2 (2.83)
$.20 \leq p < .30$	12 (11.13)	6 (6.41)	2 (2.46)
$.30 \leq p < .40$	20 (19.48)	8 (11.21)	7 (4.30)
$.40 \leq p < .50$	24 (23.93)	11 (13.78)	8 (5.29)
$.50 \leq p < .60$	23 (24.49)	16 (14.10)	5 (5.41)
$.60 \leq p < .70$	34 (37.29)	25 (21.47)	8 (8.24)
$.70 \leq p < .80$	47 (42.86)	24 (24.67)	6 (9.47)

Chi-square = 8.356, df = 12, $p = 0.870$.

above and beyond an indirect influence, which was accounted for by the temperature-wind velocity formula.

Relative Humidity

The relationship between percent capture and RH was variable to the extent that a 13-point moving average was required to portray the association with a minimum of confusion. The maximum percentage of catch occurred at about 79 percent RH (fig. 4); that level was, therefore, accepted as a baseline representing no inhibitory effects of RH on flight activity. The data were then retabulated into contingency tables of capture nights and total nights cross-classified according to observed percentage of RH versus the probability of capture. Data were again divided into two "replicates" of 6 years each and grouped to provide a reasonable frequency of total nights within each class. Percentages of capture were determined, transformed to arcsin $\sqrt{\text{percent}}$, and subjected to a factorial analysis of variance.

Results (table 8) indicated that percent capture did not differ significantly over the range of RH from 60 to 100 percent. However, 59 percent RH or lower significantly depressed percent capture. The interaction was negligible for all practical purposes (F = 0.68, p = 0.64), which was evidence that the effects of

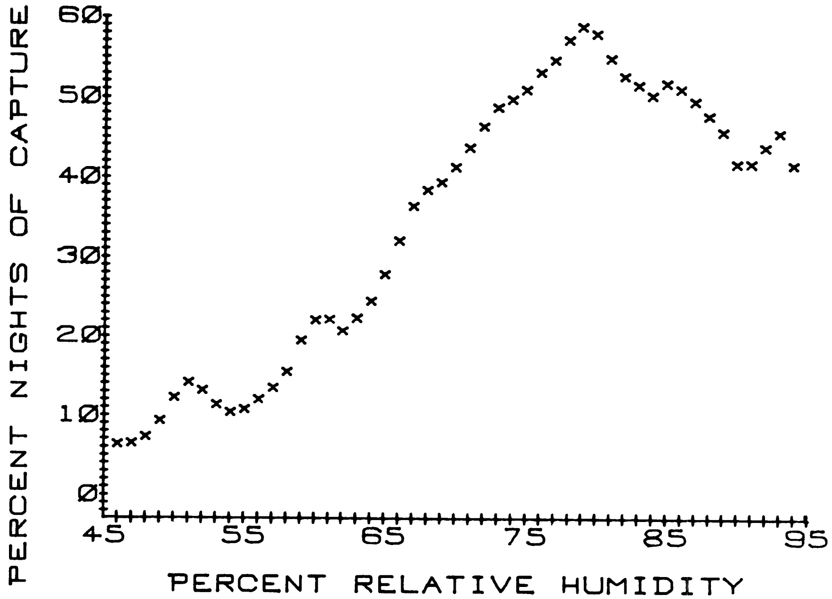

FIGURE 4.—Thirteen-point moving average of percentage of trap nights during which at least one beetle was captured as affected by relative humidity at 8 p.m., 1956–67.

TABLE 8.—*Arcsin* $\sqrt{\textit{percentage of capture}}$ *as affected by probability of capture and percent relative humidity in 1956–67*

Probability of capture (p)	Relative humidity					Mean
	≤59	60–69	70–79	80–89	90–100	
	Percent					
$0 \leq p < 0.10$	2.2	9.9	7.4	11.4	7.8	7.8
$.10 \leq p < .30$	5.3	29.2	27.2	10.8	21.8	18.8
$.30 \leq p < .50$	35.4	43.9	53.4	44.0	32.2	41.8
$.50 \leq p < .70$	43.7	55.8	63.9	57.7	51.9	54.6
$.70 \leq p < .90$	70.8	75.4	67.0	77.3	72.3	72.6
$.90 \leq p < 1.00$	75.4	75.4	80.6	78.7	77.3	77.5
Mean	38.8	48.2	49.9	46.6	43.9	

humidity (or lack thereof) were similar over all levels of temperature or wind velocity.

Because the means for RH classes in table 8 followed the same general trend as in figure 4, the procedure described for barometric pressure data was also applied to RH data to doublecheck the hypothesis of independence among the observed frequency of capture nights over the range of 60 to 100 percent RH. Chi-square values were 9.02 and 14.29 with 9 df for distributions of primary and concomitant frequencies, respectively, within limits of 10 to 90 percent probability of capture and 60 to 100 percent RH. Thus, both analyses agreed that an RH above 60 percent did not affect the probability of capture.

The wide base of the 0 to 60 percent RH class, the relatively low frequency of capture nights within the subclasses (5.7 percent of all capture nights), and the concentration of most data within the 0 to 10 percent and 90 to 100 percent probability subclasses precluded study of relationships within the 0 to 60 percent RH subclass. Therefore, no attempt was made to adjust the temperature-wind velocity formula for the inhibitory effects of low RH on probability of capture.

Precipitation

Precipitation data were tabulated into three classes: No precipitation, 0.01 to 1.0 inch, and greater than 1 inch. Procedures similar to those described earlier for barometric pressure and RH were then followed to produce a factorial analysis of variance. The results indicated no differences in percent capture due to precipitation or an interaction between precipitation and probability of capture. Means for the three precipitation classes were 46.5, 46.0, and 44.6 percent capture, respectively. It has been observed that trap catch is drastically reduced or precluded by steady precipitation during the first 3 to 4 hours of darkness. Therefore, it appears probable that the precipitation criteria in this study have no value because the precipitation parameter was not confined to the period of time when capture of beetles occurred.

Effects Of Weather On Daily Catch

Probability Of Capture Versus Numbers Captured

During all years of the study, the number of beetles captured per night was extremely variable, and increased or decreased sharply from night to night. The catch data were subjected to a regression analysis to study the association with probability of capture. It was decided to confine observations to those nights when the probability of capture was between 10 and 90 percent, inclusive, to avoid the overwhelming preponderance of data at the lower and higher extremes of probability. The probability data (the independent variable) were transformed to arcsin $\sqrt{X}$ and the catch data to log $(y+1)$ to improve linearity. Data from 862 nights were analyzed.

Regression according to the formula

$$\log(\hat{Y}+1) = -0.71843+0.031215 \arcsin\sqrt{X}$$

explained a significant proportion (41 percent) of the variance among catch data. The regression curve and its 95 percent confidence limits are given in figure 5. In general, catch tended to increase significantly with increasing probability of capture, but the response was extremely variable. Figure 5, therefore, has no value for predictive purposes; however, it is highly descriptive of observed results and is included solely for that purpose.

Change In Probability Of Capture Versus Change In Catch

Much of the variation in figure 5 was undoubtedly caused by seasonal variations in population densities. This effect on the data for 1960 and 1961 (the years during which the traps were serviced daily) was minimized by use of the procedure described by Williams (*8*) and amplified by King (*5*), whereby each daily catch is expressed as a difference between the logarithm of the current day's catch minus the logarithm of the previous day's catch. All days for which the preceding or current catch was zero were omitted because subsequent catches could not possibly decrease. Likewise, all days for which probability of capture was less than 90 percent were omitted to eliminate possible aberrant values that could result during periods that were unfavorable for

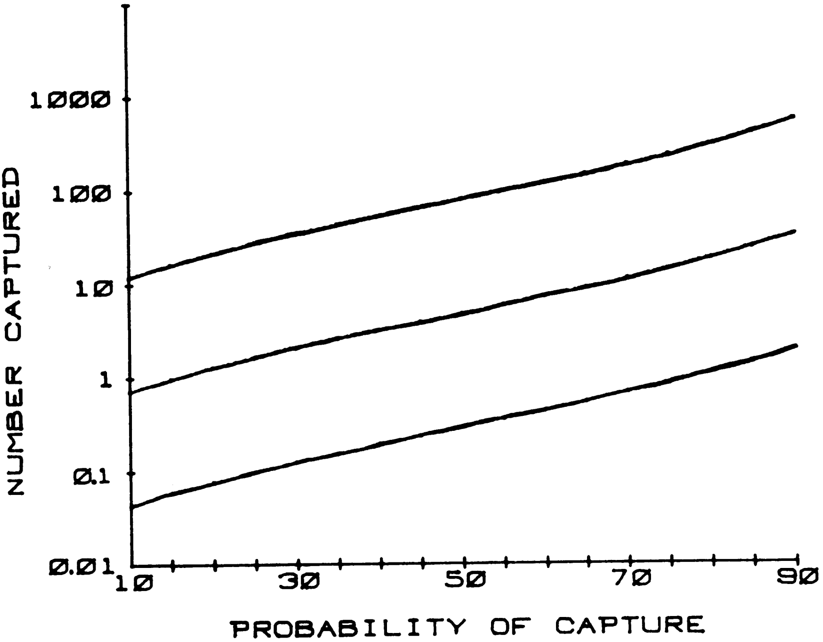

FIGURE 5.—Mean and 95-percent confidence limits of number of beetles captured per night as affected by probability of capture, 1956–67.

flight. For example, an increase in catch from 1 to 10 during January should not be considered equivalent to an increase from 500 to 5,000 during July. This elimination process left 186 observations available for study. The resulting changes in logarithms (Δ logs) of catch were considered an index of activity changes. These data were treated as the dependent (Y) variable to study possible regression with the concurrent change in probability of capture (hereafter designated as ΔP) as the independent variable. The data are illustrated in figure 6.

As expected, average activity ($\Delta \log Y$) increased significantly as ΔP increased. However, the individual responses to ΔP were quite variable. When the regression formula was used to convert all observed $\Delta \log Y$ values to adjusted values for $\Delta P = 0$, the data appeared to consist of two separate distributions. The lowest 167 points closely approximated a normal distribution, 13 of the 14 highest points occurred in an isolated clump, and 5 points of doubtful affinity occurred between the two distributions. To test whether the distinction was apparent or real, the data within the interval $-0.05 \leq \Delta P \leq +0.05$ were divided into two groups consisting of the 11 highest points and 136 remaining lower points. (This interval was selected because it provided approximately

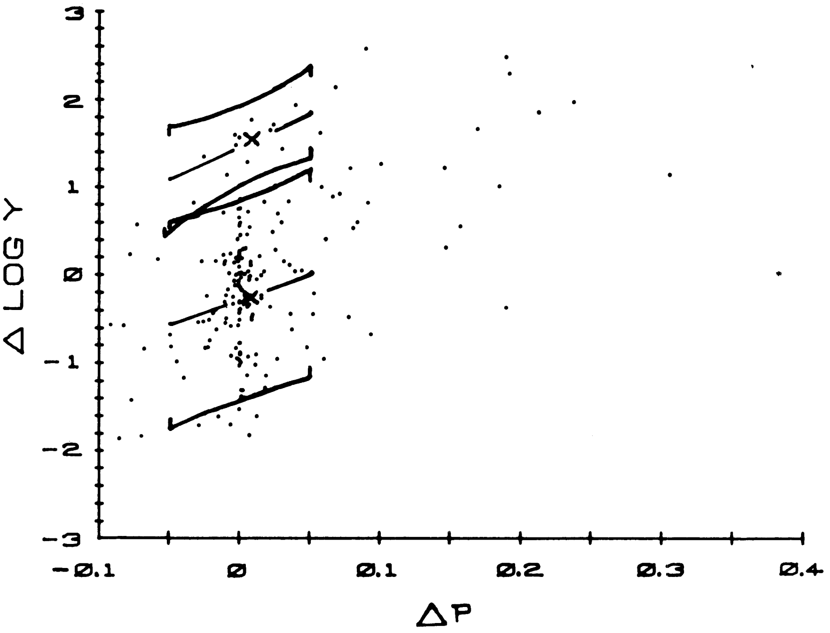

FIGURE 6.—Relationship between daily change in logarithm of catch (Δ log Y) and daily change in probability of capture (ΔP), 1960–61. (See text for explanation of regression lines and confidence limits.)

symmetrical distributions about both bivariate means and also excluded four of the five points of doubtful affinity.)

Linear regression techniques were used to estimate regression curves and 95-percent confidence limits of predicted values for both the upper and lower distributions. The means and confidence limits are indicated by the *X*'s and brackets, respectively, in figure 6. A single point from the lower distribution intruded within the confidence limits of the upper distribution, but that point was of doubtful affinity in the first place. The confidence limits between groups overlapped only for about 20 percent of their range. This was considered almost conclusive evidence of variation in flight activity above and beyond what can be accounted for by probability of capture or seasonal variations in population densities.

EVIDENCE OF MIGRATORY FLIGHT ACTIVITY

Southern potato wireworm beetles are known to be capable of extended flights under proper conditions, since Day and Reid (*1*) reported catches in traps on islands, on rafts in open water, and on a 100-ft high tower. Conversely, Onsager and Day (*6*) were unable to attribute an effect of a BL trap to distance farther than

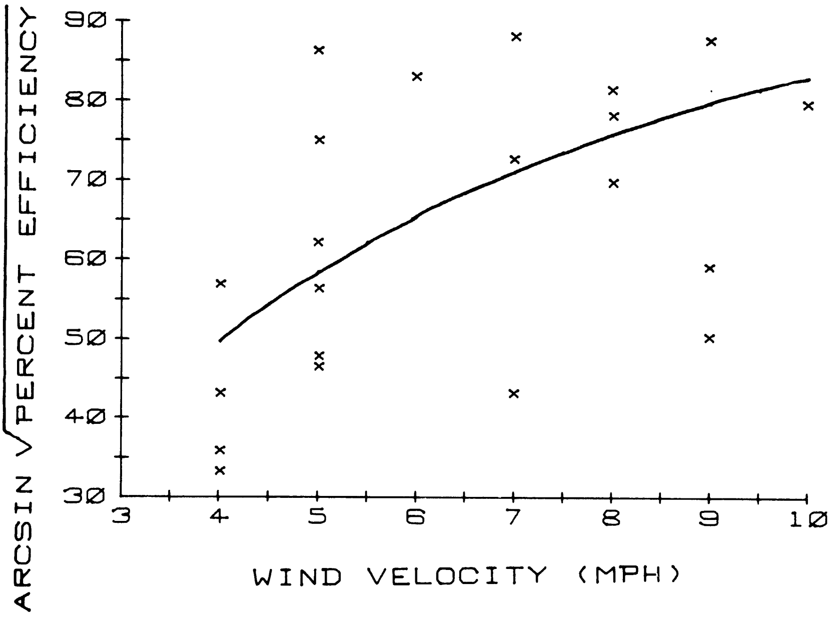

FIGURE 7.—Relationship between wind velocity and trap efficiency, 1960–61.

35 to 53 ft from the bulb. Day et al. (*2*) reported that large catches (as much as 9,800/trap) usually occurred on warm, humid summer nights within 72 hours after a rain. On the other hand, they reported an average nightly catch of only 334 during June through August, so relatively few beetles were captured on the majority of nights. The most plausible explanation of periodical high catches is the existence of what has been referred to by some authors as "dispersal" flight or "migratory" flight activity, during which entire insect populations respond to a common stimulus. Such activity, if stimulated by factors other than those that govern "spontaneous" or "trivial" flight, would periodically bring unaccountably large numbers of beetles under the attractive influence of a BL trap.

Catch records preceding the 26 observations in figure 6 where $\Delta \log Y \geq 1$ were examined in detail to determine if any of the 26 responses could be attributed to a "rebound" effect of normal catch for a period resuming after a night of abnormally low catch. Only five such possible "rebounds" were detectable (one was within the interval $-0.05 \leq \Delta P \leq +0.05$). In four cases, catch preceding the night of interest was so variable that judgment was withheld. The remaining 17 cases, however, consisted of nights when catch was dramatically in excess of normal catch for the period. The author, therefore, believes that the phenomenon of migratory flight does exist in the biology of southern potato wireworm, and that figure 6 is evidence that such activity occurred at least 17 times during 1960 and 1961.

When viewed in light of the theory of migratory flight activity, figure 6 is in close accord with results of both inductive reasoning and previous experimentation. Significant increases in probability of capture could very conceivably increase $\Delta \log Y$ by 1 or less (increase catch as much as 10 times) as a result of increased trivial flight activity. However, $\Delta \log Y$'s of about 1.1 to 2.5 (equivalent to increases of 12.5 to 300 times) are most apt to occur as a result of migratory flight activity, especially when such a dramatic increase in catch is associated with little or no change in probability of capture. Greater $\Delta \log Y$'s are unlikely because migratory flights occurred during periods of the year when all catches were relatively high. A $\Delta \log Y$ of 3 would represent a new record catch if 10 or more beetles had been captured on the previous night.

Onsager and Day (*6*) determined that populations of beetles just beyond the effective radius of a light are gradually depleted by operating a trap for several consecutive nights. Theoretically, on nights during periods of constant probability of capture ($\Delta P = 0$) when migratory flight activity does not occur, catch should progressively decline ($\Delta \log Y =$ negative) because beetles in the immediate vicinity of the trap are captured faster than they are replaced (if indeed they are replaced) by immigrants engaged in trivial flight. This theory is supported by the bivariate means of the aforementioned 136 observations within the interval $-0.05 \leq \Delta P \leq +0.05$ in figure 6. The mean ΔP was 0.000728 and the mean $\Delta \log Y$ was -0.2726, which implied that the average catch on nights when $\Delta P = 0$ was slightly less than 53.4 percent of the catch on the preceding night. The mean $\Delta \log Y$ can be divided by the slope ($b = 5.8122$) of the regression curve to estimate that ΔP must theoretically increase by about 0.047 each night in order to maintain a constant catch ($\Delta \log Y = 0$). Assuming zero immigration, 53.4 percent represents the average proportion of total available beetles that escaped capture each night. Trap efficiency, therefore, averaged 47.6 percent. This conclusion is in accord with nine estimates of trap efficiency between 28.4 and 61.6 percent, inclusive, reported previously by Onsager and Day (*6*) and obtained by a completely different method.

Onsager and Day (*6*) determined that beetles attracted to the bulb but not captured on a given night remained very close to the trap and, thus, were subject to capture on subsequent nights. If a night of migratory flight or high trivial flight activity with associated high trap catch is followed by nights of little or no flight activity that brings new beetles within the effective radius of the trap, the nightly catch is expected to decrease progressively until the next sharp increase in flight activity. During the interval between increases, the trap catch should consist primarily of beetles that escaped capture on the previous night (or nights), remained in the immediate vicinity of the trap, and eventually were captured while engaged in trivial flight.

The catch data for 1960 and 1961 were examined for intervals of 4 days or more during which catch was relatively low on the first night, relatively high on the second night, and successively much lower on subsequent nights. A total of 20 such intervals that ranged in length from 4 to 8 days were found during May through October (11 intervals contained nights when $\Delta \log Y \geq 1$). Weather records for the first 3 nights in each interval were subjected to analyses of variance to identify weather factors associated with the marked increase in catch that occurred on night 2 of each interval.

In general, results were not conclusive. All three measurements of temperature averaged significantly higher for night 2 than for night 1, which could at least partially account for increased catches on night 2. However, there was no such increase between nights 2 and 3; this could partially account for reduced catches on night 3, at least within those intervals when temperature remained constant or decreased from night 2 to night 3.

No significant differences were detected among other weather factors. However, precipitation averaged progressively less for each night in the sequence, and the data (table 9) suggest that influences of precipitation may have prevailed over expected responses to temperature. Precipitation was recorded on 29 of the 60 days represented in table 9. Precipitation was recorded for only 101 of 364 total days of record during May through October of 1960 and 1961. The probability that 29 or more of 101 total rainy days would have been selected by chance in a random sample of 60 out of the 364 possible days is 0.0003. Because the days in table 9 were selected entirely on the basis of trap catch, it is highly probable that precipitation did indeed influence catch. As implied earlier, precipitation during daylight hours could prompt a very high catch the following evening, precipitation between sunset and midnight could severely reduce or preclude trap catch, and precipitation after midnight could result in a very high catch on the following evening.

Although the distribution of precipitation within days of table 9 is not available, precipitation could conceivably have caused the

TABLE 9.—*Temperature at 8 p.m., precipitation during 24-hour periods, and number of beetles captured during 20 three-day intervals described in the text, May through September, 1960 and 1961*

Interval	Night 1			Night 2			Night 3			Total precipitation
	Temperature	Precipitation	No. captured	Temperature	Precipitation	No. captured	Temperature	Precipitation	No. captured	
	°*F*	*Inches*		°*F*	*Inches*		°*F*	*Inches*		*Inches*
1	79		126	82		720	79		544	0
2	76	0.12	44	80	0.66	1944	80		522	0.78
3	77		388	79		2048	80		254	0
4	72	.14	504	72		2220	72		796	.14
5	76	.04	66	78	.31	3810	78	0.08	2032	.43
6	80		544	82		852	80	.74	96	.74
7	75		25	80	.08	680	79		114	.08
8	78	.09	6	74		3820	69		460	.09
9	73	2.60	61	74	.03	3160	74		2140	2.63
10	70		16	72		144	74		16	0
11	76		38	76		1380	76	.02	444	.02
12	70		52	77	.05	525	74	.51	110	.56
13	92	.02	108	73	1.07	536	71		428	1.09
14	73	.33	194	74	.35	592	80	.01	216	.59
15	84		124	88		232	80		72	.97
16	73		1	79	.39	128	82	.20	111	.22
17	71	.92	50	80	.05	840	81		600	.81
18	75	.09	17	74	.13	380	74		220	.39
19	73	.75	57	77	.03	440	78	.03	260	
20	73	.39	17	76		700	76		280	

observed variation in catch during 15 of the 20 three-day intervals. Thus, while conditions that stimulate migratory flight activity could not be defined quantitatively by the parameters included in this study, the preponderance of evidence suggests that the phenomenon of migratory flight activity does exist, and that such activity is associated with precipitation.

EFFICIENCY OF BL TRAPS

If beetles enter the effective radius of BL bulbs sporatically, primarily while engaged in unusually high levels of flight activity, and remain there under the attractive influence of the bulb until they eventually become captured in the trap, then trap efficiency can be estimated by using statistical techniques developed for removal trapping. The effective radius of the trap can be considered the boundary of the area being trapped. The number of beetles that enter the area during high levels of activity plus the number that avoided capture on the previous night can be considered the total number available for capture until the next period of high activity. If high activity and high catches occur only at irregular intervals, the catch on interim nights should progressively decline. The interim catches can then be used to estimate the total number of beetles available on the preceding night of migratory flight, as well as the average trap efficiency.

The most serious objection to removal trapping techniques is that a stable population during the trapping period is assumed, with no significant natality, mortality (other than by trapping), emigration, or immigration. While no evidence to date shows conclusively that emigration absolutely does not occur or that immigration does not occur during periods of low flight activity, no evidence refutes the theory that relatively insignificant numbers of beetles are involved in the two processes. In the interest of proceeding, the author is willing to accept all necessary assumptions, with the understanding that results will be considered as interesting conjecture based on insufficient evidence for definite conclusions.

The 20 intervals of table 9 were each extended to include all subsequent nights during which catch declined successively. Data were then analyzed by the method of Zippin (*9*), a maximum likelihood method that estimated, for night 2 of each interval, the efficiency of the trap, the total number of beetles present, and the variance of each estimate. The data and results for intervals 8, 9, and 16 of table 9 are given in table 10 as examples. Interval 9 was the longest observed period of successively declining catch.

TABLE 10.—*Results of statistical method of Zippin* (9) *applied to selected intervals of decreasing catch*

Night of interval		Number of beetles captured on successive nights of indicated interval (from table 9)		
		8	9	16
2		3,820	3,160	128
3		460	2,140	111
4		54	930	54
5			510	40
6			245	
7			20	
			3	
Trap efficiency	$\hat{\bar{X}}$	88.0	50.0	33.2
	$S^2_{\bar{X}}$	0.238	0.221	12.25
Estimated number present on night 2	$\hat{N}$	4,341	7,063	416
	S^2_N	8.3348	69.2	576

Intervals 8 and 16 were the least variable and most variable intervals, respectively, as indicated by their coefficients of variation. Presumably by coincidence, intervals 8 and 16 also provided the highest and lowest estimates, respectively, of trap efficiency (88 and 33 percent, respectively). The average estimated trap efficiency was 64.5 percent, so their results compared favorably with previous estimates.

The estimated trap efficiencies next were transformed to arcsin $\sqrt{\text{percentage}}$, and transformed values were examined for possible correlation with weather characteristics on night 2 of each interval. With the exception of wind velocity, the coefficient of correlation between weather characteristics and estimated trap efficiency did not approach the magnitude required for significance at the 5 percent level of error. The observed relationship between wind velocity and trap efficiency (fig. 7) was best described by the formula:

$$\text{arcsin}\sqrt{\text{percentage of efficiency}} = 13.42 + 22.61\ (\log_e \text{wind velocity}),$$

and 37.42 percent of the observed variance among estimated efficiencies were attributable to regression on wind velocity. The suggestion that trap efficiency increases with wind velocity is reasonable (at least, within the limits of fig. 7) if beetles become increasingly less capable of last-second maneuvers to avoid collision with the trap.

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