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TELESCOPIC OBSERVATION OF THE MOON AS A MEANS FOR OBSERVING MIGRATION OF THE ARMY CUTWORM, *CHORIZAGROTIS AUXILIARIS* (LEPIDOPTERA: NOCTUIDAE)¹

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Abstract. Nocturnal insect activity was observed through telescopes focused on the moon. Flight direction was computed and methods were developed for estimating height and determining vertical distribution. Total density was correlated with light-trap catches; effective range of a light-trap was about 7 meters. Species identification was impossible but the method was selective for larger and higher-flying insects. Characteristics of insect activity observed during periods of army cutworm abundance indicate that it orients to the west during spring migration. Activity and altitude of flight were modified by wind direction and velocity but flight direction during migration was independent of wind.

The army cutworm, *Chorizagrotis auxiliaris* (Grote), migrates from the Great Plains to the Rocky Mountains with a return of the same individuals (Pruess 1968). Like most Noctuidae, the army cutworm flies primarily at night and migratory activity is rarely noticed. Only Pepper (1932) has reported unidirectionally oriented flights. His observations were made in Montana where he recorded flights toward the southwest on three consecutive nights.

Direct observation of nocturnal bird migration presents a similar problem and a solution which might be applicable to insect studies. If a telescope is focused on the moon, any object passing through the cone of observation will appear as a dark silhouette against the moon. Lowery (1951) provides an excellent discussion of the underlying assumptions and the mathematics involved in computing the flight direction of birds. Nisbet (1959) presents simplified methods for direct, but only approximate, treatment of observations. In this paper we will discuss the special problems encountered in using the telescopic method for studying insect migration.

METHODS

We used two telescopes, a 25 mm × 15× surveyor's transit (scope A) and a 60 mm × 20× spotting scope (scope B). The telescopes were mounted on tripods or a table for stability; under windy conditions we attempted to work from sheltered locations. We chose locations where the line of observation was across open areas to minimize any biasing effect of

windbreaks or other obstacles on the altitude or direction of flight by insects. Observations were made at various locations near North Platte, Nebraska, and at Blair Picnic Ground, 12 miles east of Laramie, Wyoming. When both telescopes were used simultaneously, observers exchanged scopes every 10 minutes.

All observations were made with the telescopes focused on the moon. Depth-of-field and resolution limits for each scope were determined experimentally by swinging dealatized insects in front of a dull-colored paper background at varying distances from the telescope. Based on the army cutworm, the near and far limits for accurately plotting flight direction were 25 and 700 ft (8 m, 215 m), respectively, for scope A; 60 and 1,200 ft (18 m, 365 m) for scope B. Confirmation of limits thus obtained was impossible during actual observation.

Flight direction was determined using 16 compass directions after the method of Lowery (1951). All calculations of flight direction were based on position of the moon at the midpoint of each observation period (usually 10 minutes duration). Altitude and azimuth of the moon were determined from tables (U.S. Navy Hydrographic Office 1958, U.S. Naval Observatory 1962-64).

ESTIMATION OF INSECT ALTITUDE

Estimates of insect density by the telescopic technique are dependent upon an estimate of the altitude at which they are flying. The altitude of birds can often be determined with radar, a method which only recently has become of limited use for smaller and lower-flying organisms. Stebbins (1906) described a method for estimating altitude based on simultaneous observation of the same bird through two telescopes spaced some distance apart. Again the image displacement is not measurable with sufficient precision (if observed at all) for low-flying organisms.

To estimate height of insects, it was necessary to

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resort to indirect methods: (i) differences in numbers of insects observed between periods of observations, and (ii) differences in numbers observed during the same period with the two scopes. Since neither method has previously been described, we will present each in some detail.

Method 1

As the moon rises (or sets) we view different portions of the sky. If we assume that density and vertical distribution of insects remain constant, differences in observed densities can be explained by the altitude to which we are sampling as the moon changes in elevation during the night.

The interceptory potential of the cone of observation varies with both elevation of the moon and flight direction of insects. Assuming that all insects are flying horizontally, we can illustrate this by intersecting the cone of observation with a horizontal plane. The resultant figure is an ellipse, and the relative chance for seeing insects flying in different directions is proportional to the length of the intercepted axis. The reader is referred to Lowery (1951) for illustrations and further discussion. At a given distance, d , from the point of observation (apex of cone), the length of the minor semiaxis is always $0.009d$ where 0.009 is a good approximation of the diameter of the moon expressed in radians. The solution for any axis is

$$\frac{0.009h [(1 - \cos^2 E \cos^2 a)]^{\frac{1}{2}}}{\sin^2 E}$$

where h is ceiling altitude for insect activity, E is elevation of the moon, and a is the acute angle formed by intersection of insect flight direction with the major semiaxis. Note that a is the actual angle rather than the apparent angle used in computations by Lowery; our data had been so transformed at the time this approach occurred to us.

These axes are the bases of triangular projections of the cone of observation. Assuming a uniform distribution of insects to some ceiling altitude, we can relate the number of insects, M , seen during two equal time intervals to the respective areas, A , of the intercepted triangles. We find a value for h (in feet) such that $M_1 A_2 = M_2 A_1$. For scope A, if $700 \sin E_1 < h < 700 \sin E_2$, and allowing for truncation due to depth of field limitations, then

$$h = \left[\frac{\sin^2 E_2}{0.0045} \left(\frac{2202.1875 M_2 [(1 - \cos^2 E_1 \cos^2 a_1) + 2.8125]^{\frac{1}{2}}}{M_1 [(1 - \cos^2 E_2 \cos^2 a_2)]^{\frac{1}{2}}} \right) \right]^{\frac{1}{2}}$$

This method permits separate height estimates for insects flying in different directions. By transforming observed counts to moths intersecting the minor axis,

and neglecting the minor truncations, a rapid approximation can be obtained by solving for

$$h = 700 \left[\frac{\sin E_1 \sin E_2 M_2}{M_1} \right]^{\frac{1}{2}}$$

Unfortunately this method is useful only when h lies between the two potentially observable ceilings. Under other conditions it can be determined only whether $h \leq 700 \sin E$.

Similar solutions, with the same limitations, can be written for other assumptions about the vertical distribution. For example, for density diminishing with altitude (to be discussed), a good approximation for other than very low altitudes can be obtained from

$$\frac{M_1 (0.00000530145h^3)}{\sin^2 E_2} + \frac{3820446.6 M_2 \sin^2 E_1}{h} = 7278.56 M_2 \sin E_1$$

Method 2

The different depth-of-field and resolution limitations of the two scopes permitted simultaneous sampling of different, but overlapping, portions of the sky. If flight were near the ground, scope A would lead to more observations; scope B would be superior for detecting high-flying insects. Thus the ratio in number of observations made during the same time interval with the two scopes can provide an estimate of flight altitude for each interval.

While the angle of observation, predetermined by position of the moon, biases our chances of seeing insects flying in different directions, this factor can be neglected when estimating altitude in a single direction during any one time interval. Again if there is not reason to think height varies with flight direction, observations can be summed over all directions by transforming all observed insects to the minor axis. Three assumptions about the vertical distribution were tested.

Assumption 1: Uniform vertical distribution of insects

If insects are uniformly distributed to some maximum altitude, the number seen is proportional to the relative area of a truncated triangle projected by the cone of observations as previously illustrated. We can consider the number of insects seen as the ratio B/A and determine at what altitude of insect flight such a ratio exists. In this, and subsequent methods, we found it simplest to program various values of E and h to obtain relative visible densities for the two scopes. The ratios are plotted and height is obtained directly from the resulting graph. Fig. 1 is a graphical solution for the uniform-distribution assumption. Scope B becomes increasingly effective as elevation of the moon increases or as flight altitude increases,

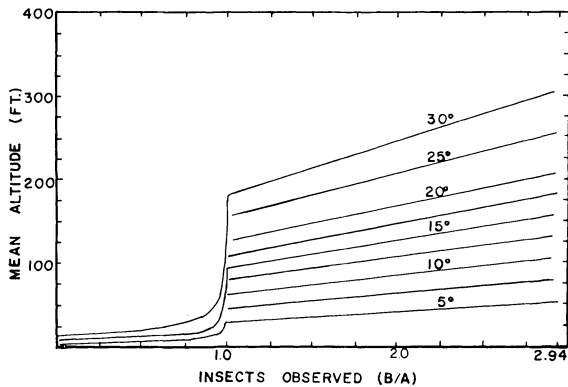


FIG. 1. Estimation of mean insect altitude from ratio of insects observed in two telescopes at different moon elevations for assumption that insects are uniformly distributed vertically to a ceiling altitude.

reaching a maximum factor of $B/A = 2.94$ when flight ceiling is at, or above, the resolution limits of scope B.

Assumption 2: Density diminishing with altitude

Most published work (Johnson 1966) suggests that density is greatest near the ground. We let density, D , vary inversely with height and again developed a graphical solution. The requisite mathematics are in the section on determination of vertical distribution and density.

Assumption 3: Normal vertical distribution

A normal distribution of insects would seem biologically reasonable for a migrating population flying at considerable heights. We set standard measure, t , equal to $\bar{h}/3$, encompassing most of the normal distribution curve and leading to increasingly platykurtic curves as \bar{h} increases. To hold population constant, we used N/t where N is set at any convenient value (in this case, 1). To find resultant curves, encompassing relative area and equivalent to number of observable insects, we selected points along the observation cone and calculated where these points intersect the height distribution. These points were expressed as ordinates of the normal curve and multiplied both by the correction factor for population and by diameter of the cone of observation at that point. By selecting a number of points for each moon elevation and assumed insect altitude, we were able to plot visible density curves. Area under each curve was determined by Simpson's rule. A graphical solution for directly estimating mean altitude is shown in Fig. 2.

Under this assumption, we can obtain a maximum theoretical ratio $B/A = 9.07$. Two solutions for mean altitude are possible under certain conditions. In such cases, observations are needed from two or more time intervals. If the ratio B/A decreases as

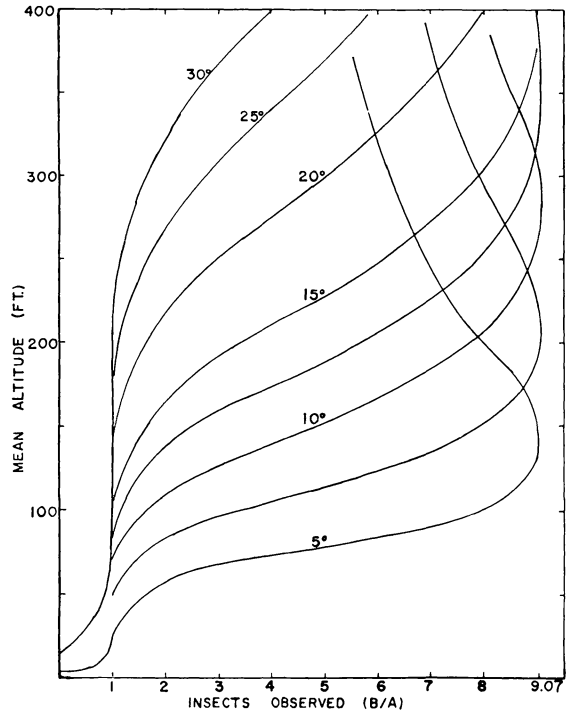


FIG. 2. Estimation of mean insect altitude from ratio of insects observed in two telescopes at different moon elevations for assumption that insects are normally distributed vertically.

elevation of the moon increases, we use the lower estimate; if the ratio increases, then the higher estimate is the appropriate one. Thus, while more than one time interval may be needed for a solution, it is possible to make a separate estimate of altitude for each interval.

DETERMINATION OF VERTICAL DISTRIBUTION AND DENSITY

All methods for estimating height are dependent upon assumptions about the vertical distribution of the insects observed. Three approaches were employed in an attempt to gain that information.

Method 1: Direct observation

We observed insects flying through a vertical light beam, utilizing the ceiling light at the North Platte Municipal Airport for that purpose. Any insect flying through this beam resulted in a brief, but intense, "flash" and densities at different altitudes were readily computed.

Method 2: Change in visible density with moon elevation

In much the same manner as altitude was estimated indirectly by comparison of observations made during two or more time intervals, it is also theoretically possible to determine something about the vertical distribution by the rate at which visible density

changes with moon elevation. At mean flight altitudes below 100 ft (30 m), 67% as many insects would be seen at 15° as at 10° if insects were uniformly distributed vertically; if insects followed a normal distribution, only 45% as many would be seen at the higher elevation. There is considerable difference in the rate of change in visible density for different vertical distributions at low moon elevations. This approach, however, was limited by the few observations possible at moon elevations below 7½°.

Method 3: Relationship between visible density and light-trap catches

Light-trap catches should be proportional to absolute insect activity. Using height estimates made by the previously discussed methods and assumptions about vertical distribution, we identify the assumption that leads to the highest correlation between computed density and catch. Adjusting observed insect density, M , to the minor axis of the cone of observation and summing overall flight directions, we compute expected visible density, P , for a constant density of insects expressed as moths per minute transecting 1 linear foot (0.3 m) at ground level.

For scope A, had actual density been 1 moth per foot per minute, then under a uniform-distribution assumption,

$$P = \frac{\pi}{3} (r^2h - 0.3164)$$

where $h \leq 700 \sin E$, $r = 0.0045 h / \sin E \leq 3.15$. Density at ground level, D_o , equals M/P . Total density above 1 ft, D_t , equals $D_o h$, h in this case taking the estimated value without limit.

Similarly, had density declined with altitude,

$$P = \frac{\pi r^2}{12h^3} [h_2^3(4h - 3h_2) - h_1^3(4h - 3h_1)]$$

where $h_1 = 25 \sin E$, $h_2 = 700 \sin E \leq h$, $r = 0.0045h / \sin E$. $D_t = D_o h / 2$.

For manual calculation, again for scope A, the following are simpler:

If $h > 700 \sin E$,

$$P = 7278.56 \sin E - 3820446.6 \sin^2 E / h;$$

If $h < 700 \sin E$, then $h_2 = h$ and

$$P = 0.00000530145 h^3 / \sin^2 E - 0.10546875 \sin E + 1.9777539 \sin^2 E / h.$$

Except for very low ceiling altitudes the last two terms are negligible and can be dropped without introducing serious errors.

Correlations were computed for light-trap catch with D_o , D_t , and with densities summed to various assumed heights for both assumptions about vertical distribution.

RESULTS AND DISCUSSION

Identification of insects

Few observations on insects are mentioned in the literature on bird migration. There is only one report of a species identification made by this technique (Williams 1958). Separation of insects into major taxa is sometimes feasible by their flight characteristics. Swarms of small "dancing" Diptera were noted at low elevations of the moon but were not observed as elevation rose above 5°. Slow, clumsy fliers, probably beetles, were also observed only at low moon elevations. Birds were frequently observed and were easily distinguished from insects. Identification of most insects, however, can be made only on a probability basis.

Detection of very small insects near the eyepiece is prevented by both depth-of-field limitations and the short time they are in the effective field of vision. At greater distances, resolution limitations prevent detection of any but the larger insects. Although there are many reports of insects present in the air at considerable heights, these reports are mostly of small forms which normally could not be detected telescopically. We are confident that our recorded observations were Lepidoptera and, more specifically, Noctuidae, since this was the only abundant taxon active when these observations were made. The relative activity of different species was estimated from catches made in black-light traps.

Observation problems

The depth-of-field limitations for near observation are relatively constant under all atmospheric conditions and for insects of greatly different sizes. Resolution limits vary with insect size, the telescope, visual acuity of the observer, and atmospheric conditions. In theory, resolution limits might be extended to a greater distance by use of a higher-power telescope but, under field conditions, this distance increases less than would be expected due to the problems of scope stability, focus, and maintenance of the "ever-moving" moon in the telescope. We suspect that a 30× scope is near the upper magnification that can effectively be used. Only when insect flight is high will greater magnification be of value; under many conditions of low flight we actually obtained more observations with scope A.

We found no significant differences in number of observations or flight direction which could be attributed to the observer. Scope A was leveled when in use and was fitted with a cross-hair which aided in plotting observed flight direction. Although scope B lacked these features, by alternating between scopes and possibly by orientation on lunar landmarks, observers recorded apparent flight directions similarly with both scopes.

Flight altitude, vertical distribution, and density

Under most conditions, density, as viewed in the ceiling light at the North Platte Airport, varied inversely with altitude but with some activity to 300 ft (90 m) or higher. However, we were not able to discriminate between taxa, small insects "flashing" to about the same extent as larger species when flying through the beam. Many more insects were detected in this manner than were observed with scopes focused on the moon. Thus, a vertical distribution for total insects, compounded from many component size distributions, may not be applicable to the single size component which we believe to have been observed in the results reported in this paper.

Different assumptions about the vertical distribution of insects led to different height estimates but had little effect on computed total densities. Correlation of light-trap catches with total density was slightly better for a uniform-distribution assumption ($r = 0.875$) than for the assumption that density diminished with altitude ($r = 0.828$). Under the diminishing-density assumption, a slight error in estimating altitude can at times result in a sizable error in the density estimate. Correlations were not improved by taking density only to some given altitude on the assumption that high-flying insects would not be attracted to the trap. While there is no reason to believe that a trap is attractive to insects flying at all altitudes, we rather think that what goes up must come down and thus at some time come within the effective range of the trap.

There was some evidence that during periods of army cutworm abundance the vertical distribution must have been rather complex. It was not unusual to obtain fewer observations as moon elevation increased to 10° – 12° but a subsequent increase again up to 15° – 20° . This would suggest that one portion of insect activity (nonmigratory?) was near the ground with another portion (migratory?) occurring at greater altitudes.

Johnson (1969) discusses a log density on log height profile; this vertical distribution would seem most applicable to smaller insects and was not further investigated. Johnson also discusses the possibility that different species of Noctuidae may have definite vertical distributions with each species flying at a "preferred" height; our results provide no evidence in support of this idea since altitude varied greatly from night to night. We do not mean to imply that any of the assumptions made in our analyses accurately reflect the true vertical profile; they probably do not. But unless clearly inappropriate, as was the case with some observations made in Wyoming, little seems to be gained by making more elaborate, but equally unconfirmable, assumptions; the simple, albeit erroneous, assumption that vertical density is

uniform at all heights is not likely to lead to serious errors in comparing data on a relative basis.

Best altitude estimates, at least in terms of consistency, resulted from the ratio of insects seen in scopes A and B when used simultaneously. Under many conditions, approximately the same number of insects will be seen through either scope. It is usually necessary to make observations over a period of 1 hour or longer, starting at moonrise, to have any assurance of finding the combination of insect altitude and moon elevation which will provide both sufficient observations and a maximum scope differential for reliability in altitude estimates.

Effective range of light-traps

Hills (1968) found the attractive range of a light-trap to be about 50 ft (15 m); Hartstack, Hollingsworth, and Lindquist (1968) estimated efficiency at 38%–50%. The relationship between light-trap catch and insect density computed from observations is shown in Fig. 3. On some occasions we had two to

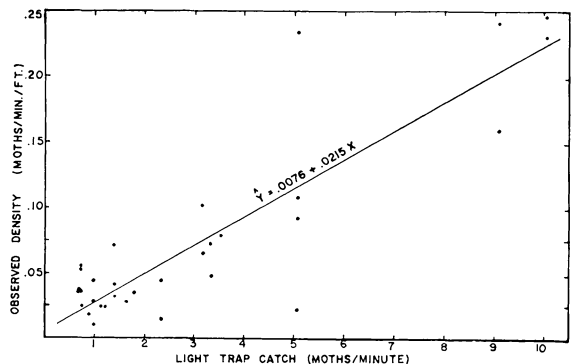


FIG. 3. Relationship between light-trap catches and observed densities of moths.

four estimates of insect density made telescopically but only a single estimate of catch for the night. These were treated as independent variables; use of means would have resulted in only slightly higher correlations. From the regression coefficient, we found that each moth per minute caught in the light-trap, assuming a 6-hour night, required the population intersecting a line 46.5 ft (14.2 m) in length or coming within a radius of 23.25 ft (7.1 m) of the trap. We would express this as effective range, equal to attractive range times efficiency. The result compares favorably with a combination of the component values derived by Hills (1968) and Hartstack et al. (1968) which would give an effective range between $50 \text{ ft} \times .38$ and $50 \text{ ft} \times .50$ or 19–25 ft (5.8–7.6 m).

Should this effective range for light-traps prove generally true, then it would be possible to estimate height by finding that altitude which gives a computed density proportional to catch. A few attempts

at substituting other values for height met with little success in increasing the correlation coefficient; apparently our altitude estimates made by unbiased methods were as good as could be obtained. Lack of agreement in a few cases between computed density and light-trap catch could be due to any of several factors—differences in effective range of the trap for different species, variation in density during the night with the period during which telescopic samples were taken not representing the mean activity for the entire night, or just plain sampling error. The degree of success obtained suggests the method has merit in the analysis of light-trap catches. It would seem highly desirable to have catches coinciding with actual observation intervals, something we failed to do.

Flight direction and height of Noctuidae

Table 1 is a summary of results obtained at North Platte during this study. All data on flight direction have been appropriately corrected to compensate for the probability of observing insects flying in different directions. Observations made with scopes A and B are combined and mean densities given. Minutes observed refer to the total for the two scopes. Mean altitude estimates are given for both a uniform-

distribution assumption ($\bar{h} = h/2$) and diminishing-density assumption ($\bar{h} = 0.29h$). Density, expressed as moths per minute transecting a front 1.6 km in length and extending to the ceiling altitude for flight, is given only for the uniform-distribution assumption. Computed densities were very similar for the diminishing-density assumption.

During the spring, whenever 16% or more of the total moth activity as measured by light-traps was attributable to army cutworm, the major flight direction was west. Flight direction was constant regardless of wind direction (though easterly winds prevailed) and velocity. Estimates of altitude were also slightly higher, on the average, when army cutworm was abundant. Altitude, however, decreased under opposing winds and density was lower when winds were above 10 knots (18.5 km/hr) from other than an easterly direction. Directional orientation was also observed when the army cutworm was absent, but these oriented flights were not constantly in a single direction. Flight with the wind for any species can seemingly occur at considerable altitudes; flight near the ground is usually less wind-oriented.

During the fall there was only a slight tendency for flight to be toward the east. Fall migration of the army cutworm seems related to movement of frontal systems (unpublished data); telescopic observation

TABLE 1. Telescopic observation of Noctuid flight in relation to army cutworm abundance, North Platte, Nebraska

Date	Light-trap catch		Total minutes observed	Total insects observed	Estimated mean altitude		Density ^c	Wind		Proportion of total insects flying $\pm 22\frac{1}{2}^\circ$ of			
	Total	% army cutworm			1 ^a	2 ^b		Direction ^d	Velocity (km/hr)	N	E	S	W
<i>Spring and Summer</i>													
June 4, 1963	3290	82%	40	18	75	70	1064	110°	19	.15	.15	.00	.70
June 7, 1963	3615	81%	55	51	25	21	1263	90°	15	.14	.11	.18	.57
May 20, 1962	1138	72%	90	19	35	26	345	110°	28	.22	.04	.02	.72
May 19, 1962	503	70%	120	78	170	117	256	110°	15	.10	.00	.00	.90
May 21, 1962	406	63%	65	4	10	7	128	290°	19	.00	.03	.32	.65
June 10, 1962	593	36%	65	7	35	23	138	110°	13	.00	.31	.00	.69
June 27, 1964	317	28%	120	19	20	50	97	140°	19	.04	.27	.11	.58
June 19, 1962	357	16%	25	10	20	18	144	20°	13	.13	.00	.00	.87
June 18, 1962	263	13%	150	61	60	60	180	calm		.02	.35	.30	.33
June 29, 1962	440	5%	98	8	40	29	118	110°	19	.13	.08	.09	.70
July 20, 1962	—	—	30	7	10		41	160°	11	.00	.00	.86	.14
July 21, 1962	—	—	70	5	15		39	320°	9	.00	.00	.85	.15
July 21, 1964	—	—	237	73	20		2254	160°	17	.47	.17	.02	.34
July 22, 1964	—	—	120	6	75		10	160°	28	.87	.00	.00	.13
July 23, 1964	—	—	120	23	15		1647	180°	15	.16	.13	.03	.68
<i>Fall</i>													
Oct. 10, 1962	1830	71%	120	21	55	44	595	110°	9	.04	.71	.06	.19
Oct. 11, 1962	1830	71%	60	34	55	44	595	340°	9	.09	.19	.45	.27
Oct. 8, 1962	1140	63%	35	5	60	60	554	220°	6	.00	.84	.16	.00
Oct. 1, 1963	356	44%	75	24	90	82	142			.01	.15	.35	.49
Oct. 2, 1963	262	43%	90	37	50	50	196	80°	7	.02	.07	.02	.89
Sept. 17, 1962	638	29%	50	12	30	25	183	110°	11	.04	.03	.86	.07
Sept. 16, 1962	843	15%	80	31	65	65	154	110°	13	.00	.02	.63	.35
Sept. 12, 1962	1262	13%	60	12	40	35	410	320°	11	.07	.38	.38	.17
Sept. 15, 1962	1198	12%	75	19	30	25	320	140°	15	.04	.00	.21	.75

^aAltitude (in feet, 100 ft = 30m) assuming a uniform vertical distribution.

^bAltitude (in feet) assuming density varies inversely with height.

^cMoths per minute transecting a front 1.6 km in length, extending to ceiling altitude for flight, assuming uniform vertical distribution.

^d40° = North, 90° = East, etc.

TABLE 2. Summary of telescopic observations of insects made June 23–27, 1964, at Blair Picnic Ground near Laramie, Wyoming

Date	% army cut-worm	Local mean time	Minutes observed	Insects observed in scope		Proportion of total insects flying $\pm 22\frac{1}{2}^\circ$ of indicated direction								Mean altitude (ft) ^b	Density ^c	Wind		
						Scope A				Scope B						Direction ^d	Velocity (km/hr)	Temperature ($^\circ$ F)
						A	B	N	E	S	W	N	E					
June 23	70%	2035	10	5	19	.00	.00	.17	.83	.00	.03	.27	.70	215	602			
		2048	10	13	24	.00	.00	.05	.95	.14	.00	.07	.80	170	961			
		2058	10	17	38	.00	.00	.00	1.00	.00	.02	.28	.70	205	1394	60°	9	57°
		2115	10	19	31	.00	.00	.23	.77	.00	.00	.00	1.00	170	1431			
		2128	10	18	126	.00	.06	.10	.84	.00	.00	.30	.70	405	7814			
		2140	10	18	59	.00	.07	.25	.68	.07	.00	.02	.91	265	2862			
		2202	10	8	28	.00	.00	.00	1.00	.06	.00	.25	.69	320	1653	100°	15	51°
		2223	10	6	10	.42	.00	.35	.23	.00	.00	.33	.67	225	961			
		2242	10	6	14	.20	.00	.40	.40	.00	.00	.19	.81	290	1109	140°	15	49°
		Mean ^a			90	110	349	.03	.04	.15	.78	.02	.01	.21	.76	252	2087	
June 24	66%	2101	10	17	44	.00	.00	.21	.79	.05	.00	.37	.58	130	554	110°	11	67°
		2140	6	1	12	.00	.00	.00	1.00	.00	.00	.29	.71	275	449			
		2159	10	3	19	.00	.00	.50	.50	.09	.13	.25	.53	370	1283	130°	19	57°
		2209	10	9	19	.18	.12	.41	.29	.00	.00	.32	.68	185	845			
		2221	10	8	13	.00	.16	.40	.45	.00	.00	.43	.43	210	729			
		2236	10	4	13	.00	.23	.53	.23	.00	.08	.52	.40	265	776			
		2301	30	6	21	.21	.00	.64	.14	.07	.04	.63	.26	285	491	230°	15	56°
Mean			86	48	141	.08	.07	.46	.39	.06	.05	.42	.47	246	732			
June 25	40%	2113	20	27	31	.15	.21	.20	.45	.14	.11	.20	.55	55	111	50°	9	66°
		2132	20	15	19	.30	.13	.54	.03	.41	.00	.39	.21	70	111			
		2203	20	8	11	.15	.12	.35	.37	.07	.11	.65	.17	90	174	60°	9	62°
		2242	20	7	9	.00	.29	.61	.10	.00	.14	.48	.38	115	253	320°	7	61°
Mean			80	57	70	.12	.20	.46	.22	.12	.10	.46	.32	82	162			
June 26–27	29%	2204	20	10	23	.00	.38	.19	.43	.18	.05	.24	.53	75	58	140°	22	61°
		2239	40	23	21	.18	.00	.44	.38	.37	.12	.11	.40	80	185			
		2337	40	10	14	.13	.00	.45	.42	.55	.21	.05	.18	150	185	130°	22	58°
Mean			100	43	58	.14	.03	.43	.40	.44	.16	.09	.31	102	143			

^aTotal for minutes and number observed; means for direction adjusted for density.

^bAltitude in feet (100 ft = 30m), assuming insects are normally distributed vertically.

^cMoths per 1.6 km per minute.

^d0° = North, 90° = East, etc.

of that migration is usually precluded by weather conditions associated with these fronts.

Observations made in Wyoming in 1964 are summarized in some detail in Table 2. The percentage of total moths that was army cutworm was estimated from light-traps operated at Laramie and Cheyenne since we had no trap in the observation area. All altitude estimates were made from the ratio of insects observed in the two scopes.

Only an assumption about vertical distribution of insects which permitted an increase in density with insect altitude fitted the observations of June 23 and 24. All height and density estimates given in Table 2 are thus based on the assumption that insects were normally distributed vertically.

The high density of insects on June 23 may be attributed to weather conditions the preceding 2 days if most of our observations were of migrating moths as we think to be the case. Rain occurred at both Cheyenne and Laramie on June 21 and 22 and the maximum temperature at Cheyenne was 59°F during that period (61° at Laramie). There was a trace of snow on the ground when we arrived the morning of June 23 but during the day it warmed to 72°. It seems likely that there was an accumulation of migratory-ready moths to the east which were in flight on June 23. Light-trap catches of army cutworm, under even more favorable flight conditions, diminished the following days but catch of other Noctuidae remained rather constant.

Height at which insects were flying had a great effect on the number actually seen but not on computed total density. Although quantitative values were not obtained, the relatively long time most insects were visible provided further evidence that insect altitude was exceptionally great. The high estimated altitudes may in part be attributed to the terrain in which these observations were made, the telescopes having been set up in a depression surrounded by higher elevations. Quite likely migrant moths, which we believe we were observing (at least on June 23 and 24), maintained to some extent their altitude as they crossed the lower area.

Apparently most insects were above the range of scope A, and possibly scope B, at low moon elevations prevailing during the early part of each night. While our assumed 1,200 ft (365 m) range for scope B is not sacred, the sudden increase in visible density, especially on June 23 and 24, at moon elevations of 18°–20° is difficult to explain unless the field of vision suddenly included a zone of greater insect density. We would be tempted to state that there was a zone between 350 and 400 ft (107 and 122 m) where density was much greater; this would be commensurate with the higher elevations surrounding the area where observations were made.

As elevation of the moon increased each night,

there tended to be an increase in percentage of total insects oriented south and a decrease in westward-oriented insects. This tendency was especially obvious June 24 when there was a rather strong southerly wind which should have prevented orientation to the south for insects flying at the heights estimated. Of the insects present, only Noctuidae could have maintained an orientation into the wind. While this provides further evidence that the telescopic method was indeed selective for this taxon, there remains some doubt that the army cutworm, for which speeds up to 15 km/hr have been recorded (Koerwitz and Pruess 1964), or any other Noctuidae, would orient in a direction in which little or no progress is possible. On one other occasion we recorded flights into a rather strong wind (May 21, 1962, at North Platte) but this flight was very near the ground, probably within the boundary layer (Johnson 1969). If these insects had been within the boundary layer prior to entering the area of our observations and had attempted to maintain a track other than downwind when flying over this depression, they would have been forced to descend. If such a descent occurred, then the percentage oriented west was underestimated since under the physical conditions prevailing during this observation period, a descent angle of only 5° would have been sufficient to result in our recording those insects in the south quadrant. Under most conditions we would expect errors in apparent flight direction due to ascending or descending insects to average out around the true flight direction, contributing only to the variance of any statement made about that direction. But under this particular set of conditions, a large error could result if most of the individuals were unidirectionally oriented but a portion descending.

A somewhat different situation occurred on June 26 when the two scopes gave quite different results for insects flying with, and against, an even stronger wind. Under most conditions we had too few observations to make any valid separate estimates of height or density for insects flying in different directions. On June 26, if we care to make such estimates, we find that the mean estimated altitude for insects flying south and west—into the wind—is about 26 ft (8 m); for those flying north or east—with the wind—144 ft (44 m). Total densities, expressed as moths per mile (1.6 km) per minute, would be 296 and 109, respectively. It should be apparent that a relatively low density of high-flying insects can account for a large proportion of the insects actually observed. While we observed more insects flying north, this resulted from their greater altitude; actual density was much lower than for those flying into the wind but at a lower altitude and presumably within their boundary layer.

During the 4-day period covered by Table 2, the

army cutworm decreased in abundance but activity of other Noctuidae remained fairly constant. As the army cutworm decreased in abundance, percentage of total insects flying west, mean altitude, and density also declined. Again it would seem that the higher flight and strong unidirectional orientation to the west, especially on June 23, was largely due to migration by the army cutworm.

CONCLUSIONS

Observations made during periods of army cutworm abundance in the spring were consistent and differed from results obtained during periods when that species was absent. Identification to species of insects observed telescopically is admittedly impossible. However, only Noctuidae were abundant and likely to be detected when these observations were made. If a single species comprises a high percentage of all observable insects, statements about that species may be allowable on a probability basis. Since directional tendencies, and to a lesser extent height, varied with abundance of the army cutworm and were only slightly modified by other factors in the physical environment, we feel justified in drawing certain conclusions.

Flight of the army cutworm during the spring is predominately from east to west and flight direction is not modified by wind direction or velocity. Flight altitude, however, decreased under opposing winds and density was lower when winds were above 15 km/hr from other than an easterly direction. Wind would seem to limit only the extent of migratory activity. The navigational system which enables these moths to maintain the proper orientation remains unknown.

Directional orientation also exists for other Noctuidae, but that orientation seems in part to be influenced by wind. High flight seems always to be with the wind but flight at low altitudes can be made into rather strong opposing winds.

The army cutworm, having completed the return

migration in the fall, apparently is no longer unidirectionally oriented. Observations of the fall migration itself, however, were not obtained.

The techniques described are useful only when a large number of observations can be made during short time intervals; only relatively large and high-flying insects are likely to be observed at all. Our experience causes us to believe the method is limited in application and more specific than our ability to identify species would imply. Yet for the situation with which we were confronted, it provided a means for directly observing a nocturnal insect migration.

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