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Design and Efficiency of Mosquito Traps Based on Visual Response to Patterns

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Introduction

Extensive investigations on the biology and control of biting flies were conducted in northern Canada from 1947 to 1953 (Brown, *et al.*, 1951; Haufe, 1952; Hocking *et al.*, 1950; Twinn *et al.*, 1948, 1950; Twinn 1950). The difficulty of assessing populations of mosquitoes both in chemical control and in ecological investigations limited the interpretation of some of the work that was undertaken. One of the primary objectives of ecological and behaviour studies was to determine the weather conditions that are favourable for attraction of mosquitoes to man. Reliable estimates of the unattracted population must, for this purpose, be obtained independently of the observer. Large catches are also important in estimating abundance when the time for individual catches is reduced to one hour or less. For these reasons a satisfactory mechanically-operated device for sampling mosquitoes in flight became essential.

We initially considered the addition of an automatic separating device to the New Jersey mosquito trap (Headlee, 1932); but in preliminary trials at Fort Churchill, Manitoba, the traps failed to attract mosquitoes during the night. This failure in the Subarctic cannot be related to species composition since *Aedes communis* (Deg.), which is readily caught at night in southern Ontario, is common in the Fort Churchill populations. It appeared to be caused either by a reversal in the behaviour of mosquitoes to light between high and low latitudes or, more probably, by the high natural light intensity during subarctic nights. There is twilight for approximately three hours at Fort Churchill during the longest day in summer, but no period of total darkness. The bright northern horizon during twilight hours may prevent mosquitoes from orientating efficiently to ordinary light traps.

In any case, there are two serious limitations in the use of light traps for quantitative studies on populations. First, light traps can be operated only at

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night whereas many species are active during daylight. Secondly, the volume of air space from which mosquitoes are attracted to a light cannot be defined. Attraction to a small, bright source of light depends on the relation between intensity and the state of adaptation in the eye. Therefore, mosquitoes might exhibit positive or negative phototaxis at variable distances from light traps depending on the intensity of natural light. Robinson (1952) discussed the latter problem and showed also how some insects may congregate at particular distances from the light source under certain conditions. He has pointed out the need for careful consideration of the behaviour of insects in interpreting samples from light traps.

The work of Autrum (1949) and Gaffron (1934) on visual responses of insects to light and to illuminated patterns suggested that attraction to moving patterns might be incorporated in the design of a trap for mosquitoes. This approach was especially promising, since insects respond to patterns of colour or light intensity only when the elements subtend ommatidial angles above a certain minimum that is characteristic of the species. Attraction to a trap using this principle can be defined in terms of a unit volume of air space with the trap at its centre. Variations in the response of insects would seem to depend on visual acuity. In practice, the accuracy of the trap would depend on a design that functions equally at all times of the day under changing light conditions. Theoretically, the basic problem in standardizing this type of trap under both light and dark conditions is the maintenance of optimum or near-optimum illumination in relation to rate of displacement of the pattern.

The purpose of this paper is to describe the development of a trap for mosquitoes using response to moving patterns as the principle of attraction; to give results of some tests on the efficiency and accuracy of the design in attracting mosquitoes under different conditions of illumination; and to briefly describe some models that trapped large samples of mosquitoes in parts of Canada where light traps were unsatisfactory.

Attraction to Illuminated Patterns

Review

Several workers (Autrum, 1949; Gaffron, 1934; Hecht and Wolf, 1929; Hundertmark, 1937; Kennedy, 1939; Knoll, 1926; Rao, 1947; Wolf, 1933; Zerrahn, 1933) have demonstrated consistent attraction in insects to moving patterns and response to flickering intensity of light. The responses described for experimental conditions in the laboratory have not been fully investigated in the field for large variations in natural light intensity, especially in species that depart from typical diurnal or nocturnal rhythms of activity. The rate of adaptation to changing light in some species may be of a very high order, in which case the rate of change of natural light would have no significant effect on attraction to a conspicuous pattern. Autrum (1950) states that eyes in Diptera have a low sensitivity to pattern discrimination but a rapid rate of adaptation mainly suited to the role of flight as the main means of locomotion. This relationship between pattern discrimination and rate of adaptation enhances the use of visual responses in the attraction of flying insects to a trap. A pattern and rate of displacement that facilitate maximum discrimination may provide attraction with adequate uniformity between day and night for some species without critical control of intensity and quality of illumination. On the other hand, if the intensity and quality of illumination significantly affect the power of some insects, even in the adapted state, to distinguish a given pattern from its background, then the amount of attraction can be kept within closely defined limits only at night and the principle of visual response has little value in a quantitative method of insect trapping.

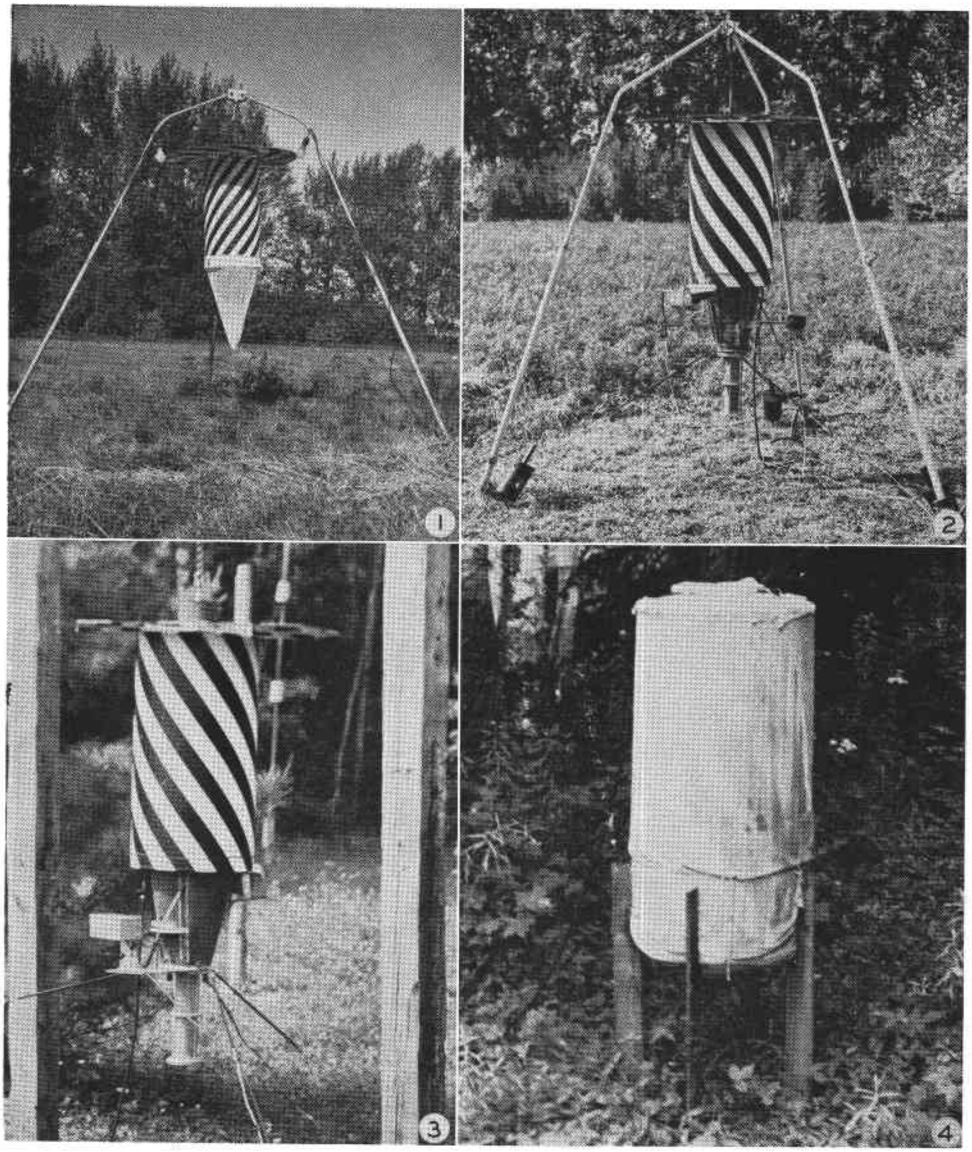
Spectral sensitivity varies between species of insect. Some insects choose colours mainly in the green to blue whereas others have a bimodal response with the greater peak in the blue to violet-purple and the lesser in the red to yellow portion (Wigglesworth, 1950, p. 146). Gjullin (1947) described the effect of clothing colours on the rate of attack of *Aedes* mosquitoes and presented the view that colours are chosen on the basis of their spectral reflectances and not by ability to distinguish colours. Brown (1951, 1954) presented data that confirmed Gjullin's view. Test colours in Gjullin's and Brown's experiments had a mutual relationship with competing patterns in the surrounding environment. Other work on the responses of animals (Rao, 1947; Knoll, 1921, 1926; Hundertmark, 1937; Schlegtendal, 1934) has indicated that competing environmental patterns in this case may cause variation in ability to select particular colours. Moreover form perception may be superior to colour perception in attraction of flying insects. If this is the case, a trap using a pattern of superior form and contrast might provide uniform or nearly uniform catches with relative independence of natural variations in intensity of illumination.

Method

Preliminary field tests were made at Fort Churchill, Manitoba, in 1951 to study the efficacy of a pattern in attracting mosquitoes and to determine the variations related to intensity and quality of illumination. A high velocity electric motor with fan was mounted at the bottom of a cylinder supported by legs (Fig. 5, D). The top of the cylinder was covered with a circular board, of slightly larger diameter, divided into three equal sectors separated by radial partitions one inch high (A). Each sector was covered by highly reflective white glazed paper. Slits $1\frac{1}{2}$ inches long and $\frac{3}{8}$ inch wide were cut in each of the three sectors to present a random pattern of rectangles on a white field (B). The number, distribution, and orientation of the slits were identical for all three sectors. A screen mesh funnel connected the lower surface of each sector to a separate cyanide killing jar mounted on the inside wall of the cylinder above the fan. In operation, the fan provided a strong suction through the slits and screen funnels and past the cyanide killing jars. Mosquitoes landing on the upper surface of sectors were sucked through the slits into the screen funnels where they were narcotized and subsequently collected in the killing jars. A light bulb was mounted six inches above the landing surface and midway in the arc of each sector with a shade that confined its illumination to the sector directly below (C). When landing surfaces were illuminated in semi-darkness, the slits appeared black in contrast to the paper surface.

The device was operated on 13 nights between June 26 and July 22, 1951, when the black-legged species of *Aedes* were near their peak of abundance. During this period at Churchill, the sun sets after 2100 hours and the period of civil twilight[4] varies from 2.6 to 2.9 hours. The sampling period for each night was arbitrarily limited to one and one-half hours between 2345 hours and 0115 hours to utilize maximum darkness. Only a portion of this period was represented by nearly total darkness, but the sampling period could not be restricted further without affecting the significance of the mosquito catches. An attempt was made to sample mosquito populations on all cloudy nights for

[4]A limit is usually fixed at a solar depression of 6° below the horizon and the time interval between this point and sunrise or sunset is called 'civil twilight'.



Figs. 1-4. 1. Simple model of the visual-attraction trap in which mosquitoes are collected in a standard sweep net. 2. Trap supported by collapsible and adjustable tripod. The shaded lights with collimators to confine the light to the cylinder at night are shown attached to the bases of the tripod legs. 3. Trapping site at Rowanton Depot, Quebec, showing the visual-attraction trap in relation to surrounding vegetation. 4. Trapping site of the suction trap operated in the efficiency trials at Rowanton Depot, Quebec.

the same reason. The trap was placed in an open area and rotated 120° at the end of each 30-minute period so that the sectors of the landing surface would be equally exposed to the windward and leeward sides each night. Since direction and velocity of wind, apart from gustiness, were fairly steady during any of the test periods, it is unlikely, with this precaution, that wind affected the overall results to any serious extent. The intensity and quality of light from a 60-watt white, frosted light bulb was used as the standard for illumination in

TABLE I
Physical characteristics of surface illumination and light sources used for attraction of mosquitoes to surface patterns

Bulb colour	Power (watts)	Light characteristics of landing surface at 6 inches from the light source		
		Brightness (log. foot-lamberts)	Incident illumination (foot-candles)	Reflection factor*
Standard white	60	2.82	208	.480
Light blue	100	3.05	404	.738
Dark blue	60	2.71	164	.724
Light yellow	100	3.11	410	.776
Dark yellow	60	2.74	176	.632
Bright white	100	3.29	617	.851

*The ratio of the brightness of a given surface to that of a magnesium carbonate block.

all comparisons. The standard bulb was compared with a light blue and a light yellow for the first five test periods and with a dark blue and a dark yellow for the following six. The physical characteristics of illumination from the bulbs are described in Table I.

Since some insects choose colours mainly in the green to blue whereas others have a bimodal response with the greater peak in the blue to violet-purple and the lesser in the red to yellow portion of the spectrum, the choice of bulbs was considered to have sufficient range in quality of light to demonstrate variations in attraction to artificially-illuminated landing surfaces.

Results

The relative abundance of species changed during the season. The early-season population complex was almost entirely composed of black-legged species, but large numbers of banded-legged species appeared in late summer as the total population gradually declined. Moreover, seasonal changes in populations correspond to changes in the general flight activity of females (Haufe, in preparation). Therefore, catches of mixed species were directly comparable for different days only during the early season when populations were predominantly represented by the black-legged group (*Aedes impiger* (Walk.), *A. punctor* (Kirby), *A. hexodontus* Dyar, *A. nigripes* (Zett.) and *A. communis* Deg.). Catches 1-11 in Table II represented this period. Catches during periods following the first 11 contained increasing numbers of the banded-legged species. Subsequent sampling in other studies in the field showed a normal seasonal decline in abundance for the general populations with increasing proportions of late-season species. Therefore the analysis of results was limited to catches during the first 11 sampling periods.

The catches shown in Table II cover a period with the variable weather conditions that are normally encountered during the mosquito season at Churchill. The landing surface was oriented in three directions with respect to wind: windward, leeward and cross-wind. Sample No. 12 is included to show that the combination of bright white, light blue, and dark blue was of the same order as that for the combination of standard white with light blue or dark blue. The lower catches for both yellows in relation to those for other qualities of light are obvious by inspection. Statistical analysis was designed to test two

TABLE II

Catches of mosquitoes attracted to patterns under different colours of illumination in relation to weather

Sample period	Weather conditions: Temperature	Moisture	Cloud cover	Trap catches per 1½ hours: Standard white	Light blue	Light yellow	Total
No. 1	Cool	Dew	Clear	105 (W)*	117 (L)*	46 (C)*	268
2	Cool	Dew	Clear	190 (C)	187 (W)	92 (L)	469
3	Cool	Dew	Clear	341 (L)	371 (C)	277 (W)	989
4	Cool	Dew	Clear	321 (W)	289 (L)	211 (C)	821
5	Warm	Humid	Nimbus	489 (C)	503 (W)	343 (L)	1335
Peak of general abundance							
				Standard white	Dark blue	Dark yellow	
6	Warm	Humid	Overcast	437 (L)	341 (C)	127 (W)	905
7	Cool	Dew	Clear	218 (W)	262 (L)	133 (C)	613
8	Very warm	Brief showers	Overcast	767 (C)	538 (W)	187 (L)	1492
9	Cool	Dew	Clear	87 (L)	104 (C)	46 (W)	237
10	Very warm	Brief showers	Overcast	648 (W)	682 (L)	284 (C)	1614
11	Cool	Dew	Clear	158 (C)	203 (W)	132 (L)	493
				Bright white	Light blue	Dark blue	
12	Warm	No dew	Clear	263 (L)	291 (C)	241 (W)	795

Cool—below 50° F.; Warm—50–65° F.; Very warm—above 65° F.
*(W), (L), (C) denote the orientation of the landing sector to windward, leeward, cross wind, respectively, for the first 30-minute period each night.

aspects of variation. First, differences were tested with Student's t to interpret variations in relation to quality of illumination. Secondly, the catches were tested for homogeneity of the populations. The results of these tests are shown in Table III. Real differences between catches were established for the dark yellow as compared with standard white and dark blue. The tests also suggested differences for light yellow as compared with standard white and light blue. X^2 tests showed that the populations sampled in successive periods were nearly homogeneous only for the standard white and light blue illumination in the first five sampling periods.

Rearrangement of the data in relation to speed and direction of wind is shown in Table IV. A difference in the average ratio of windward to leeward catches was observed for low wind velocities of zero to six as compared with higher velocities above eight miles per hour, but this difference was not statistically significant in relation to the large variation between catches for different sampling periods.

Discussion

The existence of a continuously changing species complex in populations throughout the mosquito season was recognized in the design of all field tests. Other correlations of mosquito behaviour in the field have indicated that, generally speaking, relations between flight and attraction to man are similar for the early-season species in the black-legged *Aedes* group (Haufe, in preparation). If the early-season species are equally comparable in their thresholds of visual response, considerable homogeneity might be expected in the mixed populations during the early part of the season, i.e., during the 11 sampling periods described. Statistical analysis has shown that an unexpectedly high level of variability exists even in the early populations. However, this heterogeneity may not be related to species differences in the black-legged group so much as to intraspecific differences that are related to age and previous activity. Laboratory experiments on the response of stabilized colonies of *A. aegypti* (L.) have shown that thresholds for stimulation by physical factors in the environment vary with age, starvation, and the time and amount of previous activity (Haufe, 1958). In view of the variety of environmental conditions prevailing for different sampling periods in the field tests, it is more likely that the heterogeneity between catches is related to intraspecific variations in visual response in populations over the mosquito season. If this is true, catches would tend to be selective for certain age groups depending on the quality of pattern illumination and on previous activity. Critical testing of visual response to patterns as a principle in mosquito trapping appears to require laboratory tests based on homogeneous populations, especially in relation to age and starvation. Although our preliminary field tests are inconclusive in some respects, they provide grounds for speculating on the variations that may be expected in catches attracted to patterns.

Intraspecific heterogeneity in population response may also account primarily for the lack of statistical significance of the differences related to speed and direction of wind in Table IV. Regular orientation of the trap for nightly catches would eliminate major variation in suction efficiency between sectors and in orientation of mosquito flight at high vs. low wind speeds, but it would not eliminate intraspecific variation in response thresholds for wind for consecutive nightly catches. The tests have shown that in trap design attraction to a pattern should be omnidirectional for efficient operation in variable wind conditions.

TABLE III

Comparison of catches from landing surfaces with different qualities of illumination

Comparisons		No. of samples	Probability	
Light*	Total mosquitoes		Difference ('t') test	Homogeneity (χ^2)
SW vs. LB	1446 vs. 1467	5	>.9	>.7
SW vs. LY	1446 vs. 969	5	>.2	<.001
SW vs. DB	2315 vs. 2130	6	>.7	<.001
SW vs. DY	2315 vs. 909	6	<.05; >.02	<.001
LB vs. LY	1467 vs. 969	5	>.2	<.001
DB vs. DY	2130 vs. 909	6	<.05; >.01	<.001

*Standard white (SW); light blue (LB); light yellow (LY); dark blue (DB); dark yellow (DY)

The assumption that perception of form can be made the primary factor in the function of a visual-attraction principle in trap design appears to be justified by field tests within certain limits. The difference between sectors in the quality of the surface illumination influenced attraction of mosquitoes considerably less than the difference in contrast between the landing surface and its pattern of rectangular apertures. The results of analyses in Table III indicate that attractiveness of the sectors was primarily dependent on change of retinal stimulation as the mosquitoes flew over the pattern of dark apertures. Backgrounds illuminated with yellow light were less perceptible to the mosquito than the others and the difference in attraction appeared to be inability to distinguish a contrast between the apertures and the landing surface when the

TABLE IV

Effect of wind direction and speed on mosquito catches from an illuminated landing surface

Sample period	Wind speed (mi./hr. at 30 ft. above ground)		Catches of mosquitoes/1½ hours*			Ratio of windward to leeward catches	Total
			Windward	Leeward	Cross wind		
No. 8	0–6	0–2	394	572	526		1492
9		1–3	69	97	71		237
3		3	299	379	311		989
7		4–5	201	215	197		613
1		5	72	118	78		268
2		4–6	141	166	162		469
Average			196[1]	258[1]	224	.76	
No. 4	6–8	6–8	293	259	269		821
11		7–8	153	182	158		493
Average			223	220	213	.98	
No. 5	>8	8–9	451	416	468		1335
10		8–10	555	507	552		1614
6		11–14	321	263	321		905
Average			442[2]	395[2]	447	1.12	

*Total of three, 30-minute catches for each sampling period; one from each of the white, blue, and yellow landing surfaces.

Probability of difference: [1](.6), [2](.7).

latter was illuminated with light in the red end of the spectrum. Lack of correlation between differences in catches and reflection factor, incident illumination, and brightness also accords with this view. The dark yellow fell between standard white and the blues for reflection factor, between dark blue and light blue for incident illumination, and between standard white and dark blue for brightness (Table I). The difference in catches between yellow and the other colours of illumination cannot be attributed to any of the three measurements of quality unless there are two sets of thresholds for stimulation of the mosquito eye. The only likely explanation for these results is that trapped mosquitoes responded to transitory stimulation (Wolf, 1933) by the pattern of slits on the landing surface. The low catches for yellow illumination would indicate that the perception of difference between black and yellow for the mosquito is near the lower threshold for perception of contour between contrasting surfaces.

Studies of visual responses in insects have frequently demonstrated a response to the displacement of a pattern within the visual field. For example, if bees are permitted to choose among series of patterns of the same area but of different design, the number of choices of each pattern is proportional to the lengths of their contours (Zerrahn, 1933). Sippell and Brown (1953) have shown in addition that, while airborne factors of attractiveness predominate in mosquitoes when the host is still, the visual factors predominate when it is in motion. Both Kennedy (1939) and Rao (1947) have demonstrated that mosquitoes orientate toward moving black stripes in the presence of stationary ones. The evidence indicates that the mosquito, like the honey bee, responds to stimulation produced by change of pattern during flight. Wolf (1933) found that in the bee the choices are directly proportional to flicker frequencies of fields of equal size provided the frequencies are below fusion and Wolf and Zerrahn (1935) found two flickering fields to have the same stimulating effect when the product of flicker frequency and area is the same. Since there was no significant difference in attraction to the pattern of a standard landing surface under different qualities of illumination with the exception of yellow and since agreement between catches in white and blue light is highly probable (Table III) even under variable field conditions for several days when heterogeneity in populations increases rapidly with the seasonal build-up of a complex of species and age groups, mosquitoes in flight, like bees, may be considered to respond primarily to changing patterns. If this is so, there are no serious limitations to the use of visual responses in mosquito trapping if the attractiveness of the trap is superior in competition with all other patterns in the environment under various sampling conditions. Theoretically, these conditions are fulfilled if the trap has (1) maximum possible contrast across contours of the pattern, (2) no incident illumination from point sources to interfere with the normal stimulation of the attracting pattern, and (3) a rate of movement providing optimum or near-optimum transitory stimulation. Yellow illumination was an extreme condition tested in our preliminary experiments and it, as well as other ineffective qualities, can be avoided in any trap design requiring artificial illumination.

Trap Designs

Description

A simple model of an omnidirectional trap was constructed and operated at Churchill in 1952 (Fig. 1). It consisted of a black and white spirally-striped cylinder rotating on bearings around a high velocity motor and fan. The trap was rotated by the pressure of the air stream against vanes attached to the inside wall of the cylinder. Adjustment of the vanes controlled the rate of rotation of the cylinder and consequently the flicker frequency of the stripes. Mosquitoes, orientated by the stripes to the aperture at the top of the cylinder, were forced through the cylinder by the air stream and were collected in an ordinary mosquito net attached to the base. The volume of air space sampled was proportional to the width of the black and white stripes, since attraction of mosquitoes depended on a minimum ommatidial angle subtended by an individual stripe. This model was inexpensive and efficient for sampling populations on a daily basis but manual changing of the net was inconvenient for short-period separation of catches. Necessity for frequent adjustment of the vanes was a further disadvantage. The friction in well lubricated ball bearings varied enough to influence the drag on the vanes and hence to vary the speed of rotation. Regular checking was necessary therefore to regulate the vanes for maintenance of a favourable flicker frequency in the pattern.

A more precise automatic design was developed from the simple model. This trap is illustrated in Figs. 2 and 5E. A high velocity fan mounted in a central framework created an air stream downwards through the trap. The spirally-striped attraction cylinder and disc rotate on ball bearings around a central shaft extending upwards from the central framework. Twelve black and white stripes 1⅝ inches wide were painted spirally around the circumference of the cylinder. In addition there was a similar number of black and white spiral stripes on both surfaces of the horizontal disc, necessarily expanded toward the outer and narrowed toward the inner edge. The horizontal disc contained a hole at its centre with diameter slightly less than the opening in the upper end of the cylinder to accommodate an air stream. Mosquitoes approaching the cylinder orientated toward the black and white contour lines. Inward spiralling of the pattern on the rotating cylinder directed them toward the opening at the top of the cylinder. The horizonal disc prevented mosquitoes overshooting the top of the cylinder and directed them into the air stream. The cylinder assembly was rotated at the desired constant speed by a belt from a motor mounted on the side of the framework. The upper portion of the framework of the trap was enclosed by galvanized sheet iron, the lower portion by fine copper screening. A replaceable collecting cartridge fitted into the lower end of this framework. The mechanism for separating the samples was a modification of that described by Johnson (1950). The lower portion of the cartridge was made of perforated zinc sheeting, which allowed air to pass through but retained the insects. Sixteen small aluminum discs machined to fit the cartridge were loaded in the upper end. Samples were divided at hourly or other equal intervals by the discs, which were dropped singly down a central rod. Each disc had a central collar to separate one from another and thereby prevent crushing of insects. Collecting cartridges were detachable from the trap and, also, interchangeable for transportation of samples to the laboratory. The number of discs was sufficient to accommodate changes twice daily at convenient times in morning and evening for hourly operation. The disc-dropping mechanism, mounted on the side of the trap, consisted of a selector arm connected to a magnetic plunger that was operated by electrical power through a timing device. Various models of cycle repeaters may be employed in the magnetic plunger circuit to provide sample operation at various intervals of time. An adjustable tubular steel tripod was a convenient support for the trap, especially when frequent changes of location were necessary.

The design of the collecting cartridge and disc-release mechanism in the automatic model was adopted by Harcourt and Cass (1958) in the development of a light trap and has been described by them in greater detail. Engineering blueprints of the complete visual-attraction assembly and parts are on file at the Research Station, Canada Agriculture, Lethbridge, Alberta.

Efficiency

Some observations of the behaviour of mosquitoes around the trap were made, through binoculars, from a point 25 yards away. With a stripe width of $1\frac{5}{8}$ inches and a stripe displacement rate of 160-180 per minute, mosquitoes flying in the vicinity of the trap were abruptly orientated to the stripes within a maximum distance of approximately 32 inches from the cylinder. This distance was somewhat reduced for mosquitoes flying either directly above or directly below; thus mosquitoes approximately 18 inches or more above the cylinder showed no distinct orientation and those flying at grass level were not attracted when the bottom edge of the cylinder was four feet above the ground. Observations generally indicated that mosquitoes responded to the pattern at slightly greater distances when flying below than when flying above the cylinder. The abruptness of orientation towards stripes generally increased with proximity to the stripe within the 32-inch effective range of attraction. Mosquitoes approaching within a few inches of the cylinder often circled it rapidly toward the top. They escaped the influence of the pattern by going through the opening between the upper edge of the cylinder and the lower surface of the horizontal disc and into the air stream. Therefore, the catch was a sample of flying mosquitoes that infiltrated a definite air space from any direction. When the rate of displacement of the stripes exceeded 200 per minute, the 'circling' flight increased and became erratic. At high rates of displacement circling flight was replaced in a large number of mosquitoes by 'circus movements' that prevented regular orientation toward the opening in the cylinder.

The simple model of the trap was illuminated from all sides by 40-watt electric lights during periods of low natural light intensity to maintain superior attraction of the striped pattern against the blackground. It captured large samples of all species at Churchill, Manitoba, in 1952. The net was changed hourly from 6:00 a.m. to midnight and the catch for the remaining part of the day was collected as a single sample. Hourly catches ran as high as 830 in the 6:00 a.m. to midnight periods. A catch exceeding 24,000 was taken in one of the early morning six-hour periods when favourable weather led to an unusually prolonged period of flight activity during the peak of seasonal abundance.

Investigations on the biology of mosquitoes were discontinued at Churchill in 1953. The automatic model was tested later at Rowanton Depot in southern Quebec. Mosquitoes in this area consisted of a different association of species, which appeared in order of abundance approximately as follows: *Aedes communis*, *A. fitchii* (F. & Y.), *A. excrucians*, *A. punctor*, *A. intrudens* Dyar, *A. stimulans* (Wlk.), *A. implicatus* Vock., *A. canadensis* (Theo.), and *A. vexans* (Mg.). Field tests were conducted in marginal forest consisting of scattered stands of young spruce, pine, birch, poplar, and shrubs. Because of the uneven topography, the trapping sites were not as uniform as those at Churchill.

An automatic visual-attraction trap (Fig. 3) was operated continuously from June 14 to July 3. The trap was illuminated from three directions at night by 60-watt light bulbs at a distance of 25 feet from the trap. Shields on the light sources confined the incident illumination to the trap cylinder and, also,

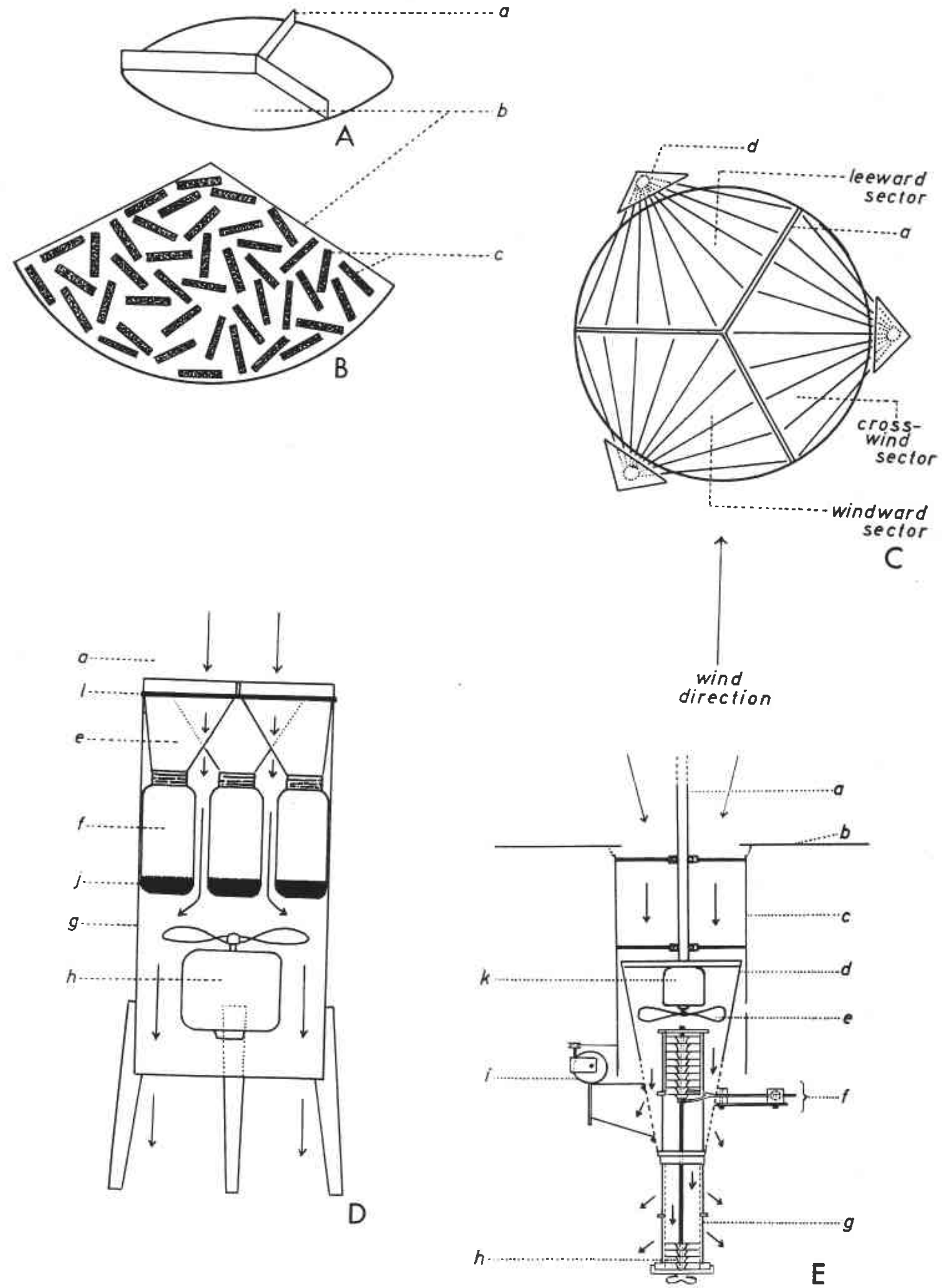


Fig. 5. A-D. The landing surface and trapping cylinder used to compare the effect of quality and quantity of light on the attraction of mosquitoes to a pattern. A, the circular landing surface with vertical dividers; B, one of the three sectors of A, showing pattern of slots; C, top view of landing surface, showing orientation to wind and arrangement of shaded lights; D, sectional diagram of the trapping cylinder. E. Sectional diagram of the visual-attraction trap with sample-separating device. (a) support, (b), horizontal disc, (c) attraction cylinder, (d) framework for collection assembly, (e), fan, (f) disc-dropping mechanism, (g) collecting cartridge, (h) disc with collar, (i) motor for driving cylinder, (k) fan motor. The cylinder turns about the supporting shaft (a) on two ball bearings.

TABLE V

Mosquito catches in visual-attraction and suction traps at Rowanton Depot, P.Q., 1954, with a preliminary estimate of trap efficiency

Date 1954	Visual-attraction trap						Suction trap					
	Day			Night			Day			Night		
	Bl[a]	Ba[b]	To[c]	Bl[a]	Ba[b]	To[c]	Bl[a]	Ba[b]	To[c]	Bl[a]	Ba[b]	To[c]
14 VI	3	0	3	57	4	61	4	1	5	9	6	15
15 VI	15	2	17	87	2	89	1	0	1	6	1	7
16 VI	81	0	81	157	0	157	2	1	3	4	3	7
18 VI	5	0	5	25	3	28	0	1	1	1	2	3
19 VI	3	0	3	54	11	65	0	1	1	14	2	16
21 VI	2	0	2	111	6	117	0	0	0	16	0	16
22 VI	6	0	6	40	6	46	0	0	0	2	1	3
23 VI	4	1	5	5	1	6	0	0	0	1	0	1
24 VI	0	0	0	92	49	141	0	0	0	1	0	1
25 VI	1	0	1	18	18	36	1	0	1	9	1	10
26 VI	4	0	4	12	22	34	0	0	0	3	1	4
27 VI	2	0	2	6	13	19	0	0	0	4	3	7
28 VI	0	0	0	4	5	9	0	0	0	2	1	3
29 VI	0	0	0	17	9	26	0	0	0	0	2	2
30 VI	4	0	4	56	76	132	0	0	0	1	2	3
1 VII	0	0	0	20	83	103	0	0	0	0	1	1
2 VII	1	0	1	5	4	9	0	0	0	2	0	2
7 VII	2	0	1	1	2	3	1	0	1	0	0	0
Total	133	3	136	767	314	1081	9	4	13	75	26	101

Species forms	$\bar{R}_r$[d]	$\bar{R}_s$[e]	Student's t for ($\bar{R}_r - \bar{R}_s$)	D.F.	Probability
Bl	0.192	0.082	1.52	30	<0.2>0.1
Ba	0.097	0.097	approx. 0	24	0.9
To	0.125	0.082	0.702	34	0.5

[a]Bl — black-legged
[b]Ba — banded-legged
[c]To — total
[d]$\bar{R}_r$ — ratio for visual-attraction
[e]$\bar{R}_s$ — ratio for suction

considerably reduced the "dazzle" effect described by Robinson (1952). A suction trap containing a minimum of attractant factors was operated 60 feet away on the opposite side of a thick growth of trees (Fig. 6). It consisted of a metal cylinder, 15 inches x 30 inches, swathed in grey cloth. A dual blower in the bottom of the cylinder provided an air stream, which trapped the mosquitoes in a small insect net hanging from a 6-inch hole in the top of the cylinder.

The catches of *Aedes* spp. in each trap were separated into 'black-legged' and 'banded-legged' forms, since the species in these groups exhibit different diel periodicities in activity (Haufe, in preparation). The latter group tends to be more nocturnal in habits. Catches summarized in Table V show the same general trend throughout the summer for both traps. The visual-attraction trap caught approximately 10 times as many mosquitoes as the suction trap with the exception of 'banded-legged' forms in the daytime. The important question is whether the attraction of mosquitoes to a pattern varies between day and night

Table VI
Comparison of catches for homogeneity in relation to species forms

Mosquito forms	Catch	No. in visual trap	No. in suction trap	Total catch	Probability based on χ^2
Black-legged	day	133	9	142	$<.5;\ >.3$
	night	767	75	842	
	total	900	84	984	
Banded-legged	day	3	4	7	$<.01$
	night	314	26	340	
	total	318	30	348	
Mixed	day	136	13	149	$>.95$
	night	1081	101	1182	
	total	1217	114	1331	

for given species. If there is variation, then significant differences should be apparent between the two traps for the ratio of day to night catches. Catches were empirically separated therefore at 0800 and 2000 hours. Tests for the significance of differences between these ratios are given in Table V. Catches recorded in italics could not be tested, since the value of a ratio becomes infinite when the denominator is O. Therefore, the sets of catches that had to be omitted are reflected in the different degrees of freedom for the three statistical comparisons. The ratios for the traps are not significantly different but there is a wide range of probability between the two species' forms and the total catch.

Testing of the traps in the field involved complex sources of variation. Most of these concern the behaviour of different species. Individual species exhibit wide variations in their diel periodicities of activity. These variations are also related to diel periodicities that are characteristic of meteorological factors. These relationships raise criticism of an empirical separation of day and night catches at certain times of morning and evening. Catches of species in which the diel increase of activity occurs near daybreak or sunset are especially difficult to assess in this respect, since variation in the day to night ratio may be a result of shifts in diel periodicity of activity. The seasonal day and night catches for the 'banded-legged', 'black-legged', and combined forms were tested therefore for homogeneity (Table VI). The probability of homogeneity was high for the total mosquito population and the 'black-legged' forms alone. The 'banded-legged' forms were heterogeneous at the one per cent level. In the latter case the day catches were extremely small. This fact, in addition to the general nocturnal behaviour of 'banded-legged' forms, suggested caution in interpreting results. The 'banded-legged' forms tended to be active in open spaces at night and to rest in vegetation during the heat of the day. The uniformity of the two trapping sites (Figs. 3 and 4) was doubtful, since the suction trap was operated on the ground nearer to trees and vegetation than the visual-attraction trap. Therefore, larger numbers of 'banded-legged' forms would be expected around the visual-attraction trap at night and around the suction trap during the day. The catches for 'banded-legged' forms (Table VI) accord with this behaviour. Catches are being compared more critically between these two types of traps under uniform conditions in alfalfa fields on level irrigated prairie.

The relation between activity within populations and factors of the physical environment, although recognized in all tests, will be described in later papers.

Insects Attracted

The visual-attraction trap caught various insects other than mosquitoes, especially in southern Alberta. No systematic analysis has been made of the collection yet but the following orders and families are well represented:—

Dermaptera		
Odonata	—	Anisoptera, Zygoptera
Plecoptera		
Hemiptera	—	Miridae, Lygaeidae
Homoptera	—	Aleyrodidae
Neuroptera	—	Chrysopidae
Trichoptera		
Ephemeroptera		
Coleoptera	—	Coccinellidae, Carabidae, Curculionidae, Elateridae
Hymenoptera	—	Ichneumonidae, Bombidae
Lepidoptera	—	Noctuidae, Arctiidae, Sphingidae, Amatidae, Pieridae, Lasiocampidae
Diptera	—	Tipulidae, Chironomidae, Tabanidae, Calliphoridae, Muscidae, Tachinidae, Scatophagidae, Asilidae

Large catches of moths were taken occasionally in daylight hours in late evening and early morning as well as during darkness. Daylight catches coincided with passage of weather fronts.

Summary

A principle of visual-attraction was incorporated in the design of a trap for mosquitoes. Tests in the field indicated that the design was efficient in capturing large numbers of mosquitoes in locations where ordinary light traps were unsatisfactory. Positive 24-hour attraction was achieved by using a black and white pattern that was superior in contrast to competing patterns in the environment. The sampling unit, in terms of air space, depended on the distance between contours in the pattern. Comparison with a suction trap under field conditions showed no significant differences in the ratio of empirically divided day to night catches. Statistical tests showed some heterogeneity in day and night samples in the two traps for 'banded-legged' forms of *Aedes* spp., but this was explained by the variation in behaviour that is known to characterize these forms. Special tests in the field on illumination for night operation showed that a relatively uniform contrast in the pattern could be maintained over 24-hour periods with artificial white light. Illumination in the yellow-red end of the spectrum reduced attraction to the pattern. Sampling of mosquitoes flying in the daytime as well as at night was an advantage in visual-attraction traps. The air space sampled remains constant for different light conditions and it can be restricted, if necessary, to accommodate studies on the flight of mosquitoes in relation to microclimate. A sample-separating mechanism provided catches at short regular intervals of the day.

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New Hymenopterous Parasites of Lodgepole Pine Needle Miners

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In rearings of lodgepole pine needle miners (mostly *Recurvaria milleri* Busck and *R. starki* Freeman) in California and Alberta an undescribed species of Ichneumonidae and two of Braconidae have commonly been recovered.

Apanteles starki new species

This species keys to couplet 51 in Muesebeck's Revision (Proc. U.S. Nat. Mus. 58: 483-576 1921) and closely resembles *A. aristoteliae* Viereck. It differs from *aristoteliae* in having longer and thinner antennae, a much longer and aciculately sculptured second tergite, and in averaging smaller and slimmer.

Apanteles californicus Mues., attacking the same host, may be separated by its very long and thin ovipositor valves (longer than the abdomen). The males may be separated by the color of the femora. In *starki* they are always black, the apices of the anterior two or four being brown or yellow. In *californicus* the femora are usually black with brown sides or brown with the upper and lower edges black. The hind femora are darkest; the front are palest, sometimes only black basally above and below. In the darkest males the hind femora are black but the four anterior femora nevertheless retain their brown sides. There are characters in the shape and sculpture of the mesonotum, scutellum, and basal abdominal tergites but individual variation eclipses the specific differences.