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AIR FLOW DIRECTION AND VELOCITY IN LIGHT TRAP DESIGN

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In tests under controlled conditions *Anopheles albimanus* and *A. stephensi* were caught in significantly greater numbers by a 4-watt ultraviolet trap with a fan-generated updraft air stream than by a similarly equipped trap with a conventional downdraft air movement. Elevation in the test chambers also affected the traps' performance, which was best near the ceiling, poor near the floor. Mesh size of the hardware cloth screens on the traps influenced only the catches of *A. albimanus* females. Survival in both traps was improved by reduced air flow. This was accompanied by a marked decrease in total captures by the downdraft trap, but with the updraft model, capture levels were maintained despite substantial reduction in air velocity. The updraft trap therefore showed greater potential for recovery of live specimens. Observations of the mosquitoes' flight behavior near the traps offer an explanation for the superiority of the updraft principle.

In recent years the Center for disease Control (CDC) miniature light trap (Sudia & Chamberlain, 1962) and the standard New Jersey trap, both with incandescent light sources, have been used routinely in mosquito light-trap studies. Ultraviolet traps (Service, 1970; Breyev, 1963) provide an alternative light source for mosquito collection. These traps represent a variety of approaches to light-trap design, but though they differ widely in size, weight, electric power requirements, and type and intensity of light, they share certain basic features. Each uses a motor-driven, rotary fan to move attracted insects down into a holding container suspended beneath the trap. With this arrangement, however, beetles and other heavy-bodied insects are easily drawn into the container where they can severely damage the fragile mosquitoes, making accurate counts and identification difficult. Hardware cloth is customarily used to exclude heavy-bodied insects from light traps but it is not always satisfactory. During recent field trials of an ultraviolet trap in El Salvador, for example, large numbers of aphodian scarabs passed through the 0.6 cm mesh guards on the traps, completely filled the collecting containers, and destroyed the mosquito catch on two successive nights.

Another approach to the reduction of unwanted insects in light trap mosquito collections is to reverse the direction of air flow. This change lifts attracted insects into a container above the trap, thus discriminating in favor of mosquitoes and similar lightweight specimens. The present study was made to determine how effectively such a trap would capture attracted mosquitoes. *Anopheles albimanus*

Wiedemann and *Anopheles stephensi* Liston adults were exposed in laboratory tests to two experimental 4-watt ultraviolet traps, one with a conventional downdraft air movement and the other with a reversed, updraft air flow.

MATERIALS AND METHODS

The mosquitoes for these tests were obtained as pupae from insectary strains and placed in netting-covered gallon cartons for emergence. The adults were supplied continuously with 10% sucrose but were not offered blood. To obtain specimens with night-time levels of activity and responsiveness for use in light-trap tests during regular working hours, the pupae and adults were held for 1 week in timer-operated photoperiod control boxes set to provide 12 hr of continuous light and 12 hr of darkness, with "sunset" simulated at a convenient hour. The susceptibility of the behavioral cycles of both species to such photoperiod manipulation has been established, and the procedure used for entrainment has been detailed by Wilton & Fay (1970).

Each experimental trap was equipped with a 4-watt BLB blacklight fluorescent lamp with a peak emission near 3650Å. The lamp was mounted horizontally at the center of the 10- x 12-cm rectangular trap entrance with a wire mesh guard immediately behind it. A 6-volt DC motor with a 2-blade aluminum fan was mounted by a bracket in the cylindrical throat of each trap. The traps were run simultaneously from one 12-volt auto battery. Tran-Bal, model 12RS4P C inverter ballasts[1]) were used to operate the fluorescent lamps from the DC power supply. Six-volt current was supplied to the motors from the same 12-volt source through appropriate resistors.

Air moved through the downdraft trap in a vertical path. A screen cylinder suspended below the trap by a cloth sleeve served as a holding cage. Location of this trap with its light source near the ceiling of the test chamber presented no difficulty. For comparable light source placement, an updraft trap with a 90° bend was designed. A cage of wire screen reinforced with sheet metal was attached by a sliding gate mechanism to its discharge end. This rigid assembly could be hung in the test chamber with the lamp only 20 cm below the ceiling. The shape and orientation of the two traps are illustrated in Fig. 1.

The traps were separately evaluated with 5- to 6-day-old mosquitoes in paired white-walled test chambers, 1.8 meters on each side. After the mosquitoes were released in the darkened chambers, the traps were started simultaneously and operated for 1 hr. Tests with *A. albimanus* and *A. stephensi* began 1.2 hr and 4 hr, respectively, after onset of the dark phase ("sunset"). For these anophelines the effectiveness of short trapping periods beginning at these times relative to "sunset" has previously been demonstrated (Wilton & Fay, 1970). At the conclu-

[1]) The Bodine Co., Inc., Collierville, Tennessee 38017. Use of trade names is for identification purposes only and does not constitute endorsement by the Public Health Service or the U.S. Department of Health, Education, and Welfare.

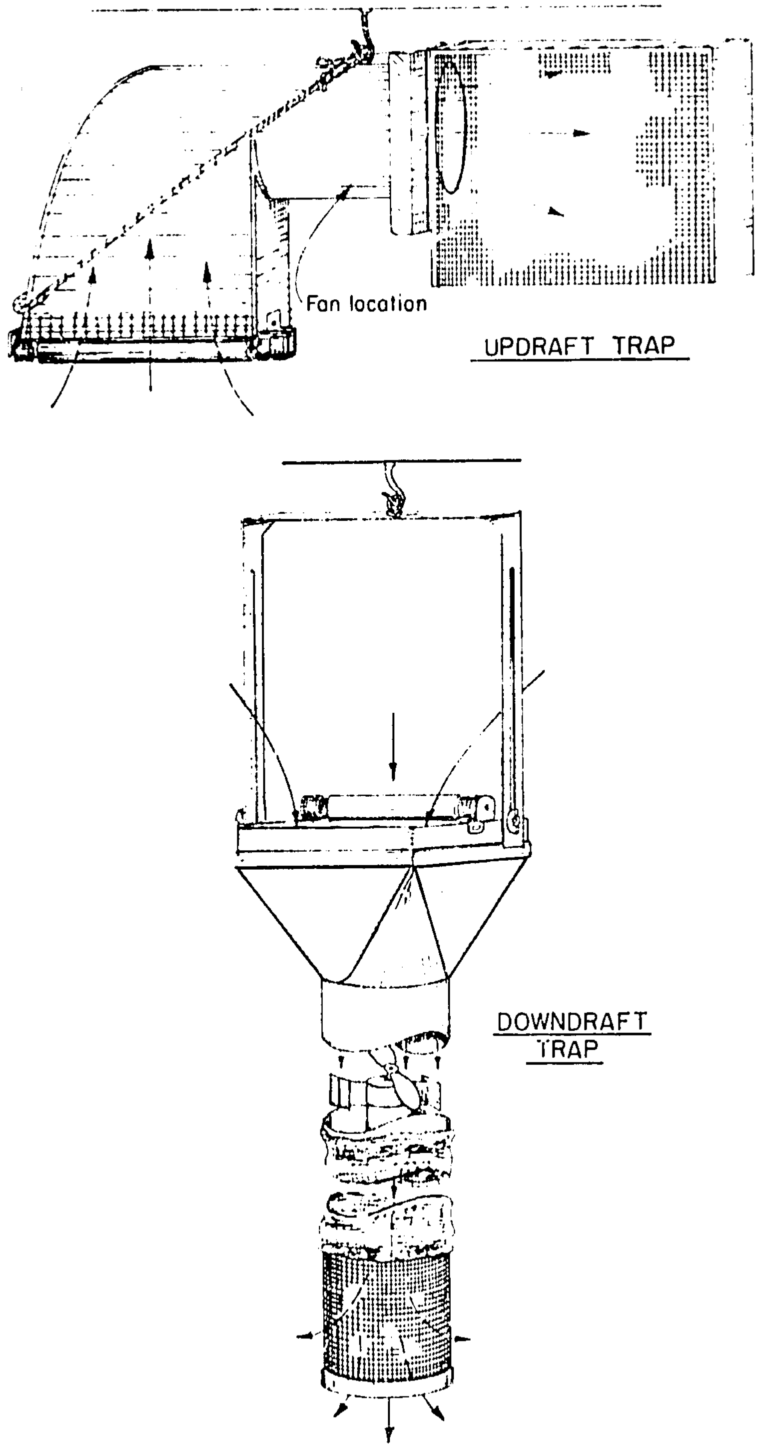

Fig. 1. Experimental traps used to compare the effects of upward and downward air flow on mosquito captures.

sion of each test, untrapped mosquitoes were collected with a hand-held vacuum cleaner provided with a trap in the intake hose. Temperature during the tests ranged from 26° to 28°.

The influences on trap effectiveness of air flow direction, vertical location in the test chamber, and barrier mesh size were studied in a factorial experiment. The traps were suspended from hooks in the centers of the chamber ceilings. Vertical placement was determined by the distance from the ceiling to the lamp. High placement was 20 cm from the ceiling, intermediate placement, midway between ceiling and floor at 91 cm, and low placement, 52 cm from the chamber floor. The hardware-cloth mesh sizes compared were 0.6 cm and 1.3 cm.

During the experiment it became evident that survival of trapped specimens was substantially higher in the straight-passage downdraft trap than in the right-angled updraft model. To determine the effect of reduced air flow on both survival and total catch, each trap was fitted with a 0- to 100-ohm variable resistor wired in series with the motor to permit regulation of fan speed. The lamp circuits were not altered. Air flow through the traps at 6 volts was measured with a vane anemometer and equated at 171 m/min by adjusting fan blade pitch as necessary. In tests with *A. albimanus*, conducted as described above, the percent catch and survival rate were determined for each trap at 6, 5, and 4 volts, which produced air flow rates of 171, 137, and 110 m/min, respectively. In addition, the performance of the updraft trap was checked at 3 volts and 87 m/min.

To separate specimens surviving capture, the entire catch was chloroformed for 60 to 90 seconds and transferred to a pint container surmounted by a netting-covered gallon carton. *A. albimanus* was found to recover well from this degree of anaesthesia and specimens able to move overnight through the inverted funnel separating the two containers were classed as survivors.

RESULTS AND DISCUSSION

Since the number of mosquitoes varied substantially from one replicate to another, percentage values, rather than actual numbers trapped, were taken as the basic data from the factorial experiment. Because the replicate means ranged so widely the basic data were transformed to the arcsin scale.

Rupp & Jobbins (1969) have previously described an updraft light trap, but they gave little information about its effectiveness. In the present study the superiority of the updraft principle is evident. For *A. albimanus* (Table I), mean captures of females by the updraft trap ranged from 42% to 72%, depending on trap elevation, whereas mean downdraft catches did not exceed 28%. Male captures were appreciably higher: 65% to 90% with the updraft trap but no higher than 56% with the downdraft model. For *A. stephensi* (Table II), mean female captures ranged from 34% to 85% for the updraft trap compared with 29% to 71% for the downdraft trap. Male captures, updraft and downdraft, were 54% to 91% and 44% to 76%, respectively.

TABLE 1

One-hour captures of 5- to 6-day-old adult Anopheles albimanus *by updraft and downdraft ultraviolet light traps*

		Updraft trap							Downdraft trap						
Trap elevation	Guard mesh (cm)	Sex	Percent trapped (Replicates I-IV)				Total number tested	Mean percent trapped	Sex	Percent trapped (Replicates I-IV)				Total number tested	Mean percent trapped
High*	1.3	♂	93.6	94.9	88.3	82.0	515	90.3	♂	67.0	54.4	48.3	58.8	414	53.9
		♀	71.7	69.3	84.0	57.3	401	72.1	♀	38.2	27.7	17.4	31.3	364	28.0
	0.6	♂	91.6	84.3	93.8	89.7	422	89.8	♂	48.1	62.1	56.9	51.8	440	55.7
		♀	67.8	56.8	53.4	47.6	364	55.8	♀	18.2	36.0	24.7	23.7	378	27.5
Intermediate**	1.3	♂	84.3	82.8	86.4	89.3	548	85.2	♂	32.8	47.2	39.8	30.8	501	38.9
		♀	52.6	60.5	74.0	69.6	412	61.4	♀	24.5	24.7	28.4	15.6	476	23.7
	0.6	♂	85.7	75.8	85.1	83.3	731	82.8	♂	41.9	46.8	47.1	29.9	683	39.8
		♀	43.1	47.6	47.4	42.7	519	44.7	♀	16.0	28.1	23.2	15.2	514	19.1
Low***	1.3	♂	41.6	75.6	69.0	72.2	500	65.0	♂	20.4	40.3	22.3	33.1	501	28.5
		♀	28.8	68.8	30.1	44.4	500	41.6	♀	12.4	18.8	12.3	17.7	441	15.4
	0.6	♂	68.4	66.7	65.0	67.6	501	67.3	♂	23.9	45.1	41.7	42.1	391	37.9
		♀	48.0	46.6	43.2	47.4	525	46,5	♀	15.7	14.9	17.7	17.5	461	16.7

* Lamp 20 cm below test chamber ceiling.
** Lamp midway between test chamber floor and ceiling.
*** Lamp 52 cm above test chamber floor.

TABLE II

One-hour captures of 5- to 6-day-old adult Anopheles stephensi *by updraft and downdraft ultraviolet light traps*

Trap elevation	Guard mesh (cm)	Updraft trap: Sex	Percent trapped (Replicates I-IV)				Total number tested	Mean percent trapped	Downdraft trap: Sex	Percent trapped (Replicates I-IV)				Total number tested	Mean percent trapped
High*	1.3	♂	93.9	89.8	95.4	85.1	399	91.0	♂	61.3	73.1	79.8	77.9	405	74.6
		♀	86.8	88.5	83.0	83.0	334	85.0	♀	55.9	66.1	83.4	58.1	434	71.4
	0.6	♂	88.7	96.7	86.7	88.8	356	90.4	♂	79.3	74.0	76.9	72.5	331	75.5
		♀	81.7	89.5	75.0	78.7	334	81.4	♀	62.5	73.0	75.0	64.0	329	67.8
Intermediate**	1.3	♂	77.9	74.0	82.3	85.4	302	79.8	♂	64.2	76.0	56.8	56.7	340	64.4
		♀	65.7	49.3	64.4	48.3	313	55.3	♀	42.7	47.1	46.7	39.3	341	44.0
	0.6	♂	70.9	63.8	62.0	75.7	521	67.8	♂	72.7	73.1	65.0	53.2	529	66.2
		♀	53.2	51.8	66.0	55.2	431	55.0	♀	48.1	42.7	44.1	27.9	408	39.0
Low***	1.3	♂	46.3	68.9	42.5	58.1	504	54.2	♂	39.7	46.8	54.3	39.4	469	44.1
		♀	36.0	51.5	44.3	42.8	549	43.2	♀	26.5	30.9	26.1	36.0	505	30.3
	0.6	♂	46.2	68.5	56.7	42.3	500	58.6	♂	43.3	66.1	58.1	27.9	450	54.2
		♀	29.0	43.1	33.0	35.8	382	33.5	♀	21.2	41.9	34.6	25.2	406	29.3

* Lamp 20 cm below test chamber ceiling.
** Lamp midway between test chamber floor and ceiling.
*** Lamp 52 cm above test chamber floor.

Although the better performance of the updraft trap was more evident with *A. albimanus*, analyses of variance revealed that differences attributable both to air flow direction and to trap elevation were statistically significant for both sexes of both species. Moreover, the results at all three elevations in the test chambers were significantly different, the order of effectiveness being high > intermediate > low. The factor of trap elevation apparently is one which should be carefully considered in any use of mosquito light traps inside dwellings or other structures.

Bartnett & Stephenson (1968) reported that, except for the very large *Psorophora ciliata*, the numbers of mosquitoes caught by outdoor New Jersey light traps were unaffected by a change from a 0.8 cm to a 0.6 cm mesh hardware-cloth barrier but that traps with the smaller mesh contained fewer beetles and moths. Mesh size in the present experiment affected only *A. albimanus* females; they were caught in significantly greater numbers with the 1.3 cm mesh. This difference seems to result almost entirely from the better catches obtained with the larger mesh at the high and intermediate elevations with the updraft trap.

Only one of the interactions among the primary treatment effects attained statistical significance. For male *A. stephensi* the effect of trap elevation had a more pronounced influence on the performance of the updraft trap than on that of its counterpart. The calculated "F" value for this interaction was 3.18. This is so close to the 5% level of significance ($P_{.05}$ = 3.29) that it doubtless represents a real effect.

The effects of reduced air flow rates on total catch and survival of *A. albimanus* are summarized in Table III. With the updraft trap, capture levels of males remained constant, and female captures actually increased with decreasing air flow until the air speed was reduced to half its original value. By contrast, decreased air flow through the downdraft trap tended to reduce the catch of both males and females. Lowered air speed resulted in improved survival of both males and females in the updraft trap. At an air flow rate of 110 m/min, the downdraft trap had a capture rate for female *A. albimanus* of approximately 19% in 1 hr. Although the survival rate of these trapped mosquitoes was high (82%), only 15 live individuals would be expected from each 100 exposed to the trap. At the same air flow, a lower survival rate (66%) in the updraft trap should still yield 50 live females from each 100 at risk because of the 76% capture rate. Predicted live recoveries from the updraft trap operated at 87 m/min would not be higher, despite an increase in the mosquito survival rate to nearly 82%, because of a compensating decrease in total captures. Sustained capture levels combined with improved survival at reduced air velocities indicate that the updraft mode of operation would be especially useful wherever recovery of live mosquitoes is an objective of trapping.

When *A. albimanus* adults were dusted with a fluorescent zinc sulfide powder which made them brightly visible in ultraviolet light, a reason for the lower efficiency of the downdraft trap became evident. Several groups of dusted mosquitoes were observed through a window in the test chamber during operation of this

TABLE III

Captures and survivals of A. albimanus *adults exposed for 1 hour to updraft and downdraft ultraviolet traps at various air flow rates (each entry based on three replicates).*

Air flow (m/min)	Updraft trap: No. tested, Male	Updraft trap: No. tested, Female	Updraft trap: Percent trapped, Male, Total	Updraft trap: Percent trapped, Male, Alive	Updraft trap: Percent trapped, Female, Total	Updraft trap: Percent trapped, Female, Alive	Downdraft trap: No. tested, Male	Downdraft trap: No. tested, Female	Downdraft trap: Percent trapped, Male, Total	Downdraft trap: Percent trapped, Male, Alive	Downdraft trap: Percent trapped, Female, Total	Downdraft trap: Percent trapped, Female, Alive
171	490	273	88.4	18.4	67.4	19.0	594	316	50.8	25.1	32.3	16.5
137	527	548	89.6	20.9	71.2	26.5	368	445	54.1	21.5	28.1	18.0
110	519	407	88.8	42.4	75.9	49.9	443	361	36.8	27.5	18.6	15.2
87	579	515	85.7	62.7	60.6	49.5						

trap, which had been fitted with a flat, white plastic cover mounted 15 cm above the lamp. Individuals which approached the lamp but managed to avoid being drawn into the trap characteristically escaped by flying upward. They collected under the trap cover where they made continual attempts to fly higher. Upward flight did not appear to be simply a reaction against the downward flow of air at the mouth of the trap, however, because the mosquitoes were not observed to fly downward in response to the comparable air flow created by the updraft trap.

These observations suggest the following hypothesis: upon encountering the air stream near the mouth of a trap, a mosquito attempts to evade it by vigorous flight activity. Its wing movements produce, in addition to forward thrust, a strong lift component. If the trap is a conventional downdraft type, its air stream must overcome the lift factor in the mosquito's flight. If the trap creates an upward-moving air stream, however, the mosquito's flight reaction contributes not to escape, but to capture. The sustained captures by the updraft trap and the lowered catches of the downdraft trap obtained when air flow was reduced are consistent with this hypothesis. Mean catches of *A. stephensi* with the downdraft trap were, without exception, higher than those of *A. albimanus*. Although this seems to indicate that *stephensi* is more responsive to ultraviolet light, it may just as well be evidence that this mosquito is the weaker flyer of the two.

In view of the encouraging results obtained with the updraft mosquito trap built for this study, more practical designs for evaluating the updraft principle under field conditions are being considered.

These studies were accomplished as part of a contractual agreement between the Center for Disease Control and the Agency for International Development.

RÉSUMÉ

INFLUENCE DE LA DIRECTION ET DE LA VITESSE DE L'AIR DANS LA CONCEPTION D'UN PIÈGE LUMINEUX À ASPIRATION

Deux pièges à lumière ultraviolette sont comparés dans leur efficacité pour la capture des adultes *Anopheles albimanus* et *A. stephensi* en essai au laboratoire. Chaque trappe se compose d'une lampe BLB 4-watt fixée à une extrémite d'un conduit de métal, l'autre extrêmité s'ouvrant sur une cage de grillage, cependant qu'un aspirateur (moteur 6-volts DC) placé dans le conduit fournit le courant d'air pour attraper les insectes. Dans un premier type de piège l'aspiration de l'air entraine les insectes vers le bas dans la cage de grillage (downdraft trap); dans un second type les insectes sont au contraire tires de bas vers le haut avec le courant d'air (updraft trap).

Les tests ont été effectués dans les chambres à parois blanches de 1.8 m de côté. Les lampes BLB sont disposées à trois niveaux : (a) le plus haut à 20 cm sous le plafond : (b) le plus central à 91 cm au-dessus du plancher; et (c) le plus bas, 52 cm au-dessus du plancher. Tous les essais ont montré que le piège lumineux du type "updraft" était le meilleur pour la prise des adultes âgés de 5 à 6 jours. Les pièges disposés sous le plafond ont donné les meilleurs résultats.

La survie des insectes capturés était meilleure dans le piège de type "downdraft", pour

une aspiration de l'air à une vitesse de 171 m/min. En réduisant le voltage à 5 ou 4 volts, la vitesse du courant d'air d'aspiration se réduit à 137 et 110 m/min et on observe une forte amélioration de la survie des insects capturés dans le piège "updraft", sans qu'il y eut réduction du nombre des insectes capturés. Mais ce n'est pas le cas avec le piège de type "downdraft" pour lesquels le nombre des captures se trouve réduit avec diminution du voltage.

Les observations du vol des moustiques autour des trappes permettent d'expliquer la supériorité du piège de type "updraft".

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