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Evaluation of a new technique for recording the direction of flight of mosquitoes (Diptera: Culicidae) in the field

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Abstract

In a study in the Gambia on the relationship between wind direction and the direction of flight of mosquitoes, high-voltage electric grids were used as screens in conjunction with suction traps. Mosquitoes contacting or attempting to fly through the grids were electrocuted. The screening efficiency of the grids was estimated to be 75–80%, and the grids had no demonstrable effect on wind speed. The traps were set up in pairs with their mouths at ground level, one trap in each pair being screened on the upwind and the other on the downwind side. In this way, the mosquitoes could be segregated into those that were flying predominantly upwind and predominantly downwind, respectively. The results indicated that some 64% were flying upwind at this level, but this proportion varied considerably over a period of days, with nightly extremes of 87 and 43%; there was little difference between species. This variation was not correlated with wind speed, but there was some evidence that the presence of moonlight led to a greater degree of upwind flight.

Introduction

The problem of recording the flight movements of small or nocturnal insects in the field presents many difficulties. When the insects are both small and nocturnal the problem is even greater. In the search for valid techniques, the principal difficulty is the obstruction to air movement created by the sort of traps that are used or the screening materials they incorporate. None of the methods previously employed for the study of mosquitoes, such as sticky panels (Gordon & Gerburg, 1945), horizontal suction traps (Horsfall, 1961), Malaise traps (Hocking, 1970), bed nets (Colless, 1959) and ramp traps (Snow, 1976), has been free of this effect on air flow.

Recently, Vale (1974) has shown that electrocuting grids can be used to provide a highly effective means of trapping tsetse flies (*Glossina*). It occurred to us that similar grids, when placed in appropriate positions, might serve as screens to convert non-directional sampling devices for mosquitoes into directional traps. The grids should have no effect on air flow past the traps, and the approach paths of the insects might therefore be assumed to be normal. We describe here the results of trials of electric grids used in conjunction with suction traps to provide directional information about the movements of mosquitoes.

Methods

The trials were carried out during the rainy season of 1975 in an area of open farmland and cleared bush near the village of Saruja, MacCarthy Island Division, The

Gambia, a description of which was given by Gillies & Wilkes (1976). Catches were made between 20.00 and 04.00 h and were limited to dry periods because of the effect of rain on the grids.

The electric grids closely followed Vale's (1974) design except that, in view of the smaller size of mosquitoes compared with tsetse flies, the wires were spaced at intervals of 5 mm. The wires, of 0·15 mm steel, were strung on aluminium frames 44 cm wide by 46 cm high and were tied with nylon thread at one end and tensioned with steel springs at the other (Fig. 1). A 240-V AC generator was used, the voltage of which was increased by a step-up transformer, as used in a commercial electrocuting fly-killer, giving about 5000 V AC. The output voltage was adjusted by inserting series resistors

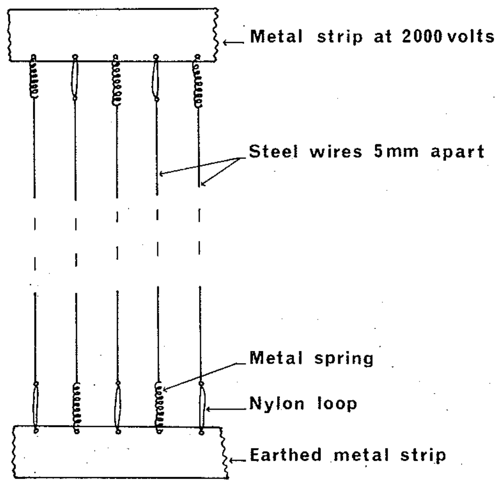

Fig. 1.—Details of construction of electric grid.

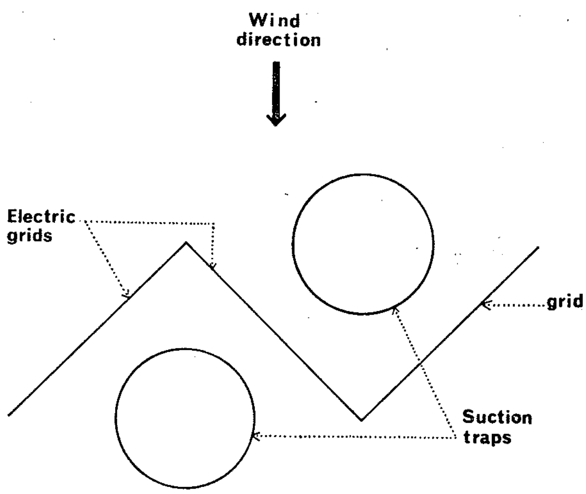

Fig. 2.—Arrangements of grids and suction traps in relation to wind direction.

in the primary circuit, lowering the input voltage until there was no spontaneous sparking in the grid; the working output voltage was just under 2000 V. For testing the grids, a switch was provided to bypass these resistors, and the sparking that resulted showed that the circuit was correctly completed. The current was probably of the order of 1 mA and was sufficient to knock down or burn up the insects but was harmless in the event of accidental contact by human beings.

The suction traps used were Vent-Axia fans 22·8 cm in diameter. These were mounted in pairs side by side with their mouths horizontal. Three electric grids were fixed to the supporting frames of each pair of traps, one grid forming a screen between the two traps and the others fixed at right angles to this screen on opposite sides of the two traps (Fig. 2; Plate IV, A). In this way, when the traps were aligned across the axis of the wind, one trap was screened on the downwind side and the other on the upwind side. Initially, traps were set up at levels of 2 m, 1·2 m and approximately 15 cm above the ground. Later, only the low-level traps were used. These were mounted above a pit $1\times1\times1$ m, from the corners of which two shallow trenches were cut to lead the exhaust air away from the traps. The pits were covered in with coarse-mesh polyethylene netting (Netlon) lined on the underside with polyethylene sheeting (Plate IV, A, B). The netting frames formed a gentle slope from the surrounding ground up to the mouths of the traps, thus smoothing air-flow over them and removing any wind-drag that could be caused by the supporting framework.

The low-level traps were set up in three pairs in flat, open ground, in a triangular pattern and separated from each other by distances of 5, 11 and 14 m. The three pairs of traps were aligned so that each of their axes differed by 60° from that of the other two. This meant that, for any direction of the wind, the catching axis of one pair of traps was always approximately aligned with the wind direction. Catches were restricted to periods when the wind across a particular pair of traps remained within 45° of the catching axis.

The absence of wind-drag effects through the screens was confirmed by tests with anemometers, one surrounded on all four sides by grids and the other unscreened.

Wind direction was recorded on a continuously recording instrument of the type described by Lewis & Siddorn (1959). The mean wind speed during the experiments, measured with a sensitive anemometer at 1·2 m, was 1·59 m/s. Simultaneous operation of an anemometer at approximately 15 cm above the ground showed that the wind speed was only 1·03 m/s at the level of the mouths of the traps.

Results

Grid efficiency

The effectiveness of the grids in excluding mosquitoes from suction traps was tested in the following way. Two traps were set up with their mouths just above ground level, one being screened off with electric grids on all four sides, the other being left unscreened. The screens were changed over from one trap to the other each night. Trials were run on 24 nights at three different sites. To test the effectiveness of the grids as mechanical barriers to flight, in addition to their action as electrocuting screens, an additional pair of traps was used, one open and the other screened as above but with the electric grids switched off. In this way, comparison could be made between the catch in unscreened suction traps and that in screened traps with the current either switched on or off.

The results are shown in Table I. They illustrate two points. Firstly, when the grids were switched on, the proportion of the catch dead in the screened trap was much higher than in the open trap. This shows that a proportion of the electrocuted mosquitoes were passing through the grid and being caught in the suction trap. If this source of error is removed by considering live mosquitoes only, it can be calculated that approximately 24% of the mosquitoes passed through the grids when the current was switched on without being killed or diverted.

Secondly, when the grids were switched off, the catch in the screened trap, relative to that in the open trap, was virtually the same as when the grid was switched on. Thus, with the trap completely screened off on all four sides and with the current switched off, the grids were apparently just as effective as a mechanical barrier in excluding mosquitoes from the trap as when the current was switched on. However, it does not follow from this that the same would have applied with traps screened off on two sides only. The effectiveness of the live grids in killing mosquitoes was amply demonstrated by the numbers burnt up and still attached to the wires or picked up dead on the supporting framework of the traps. Had the grids not been switched on during the flight experiments, it is highly likely that some of the mosquitoes would have tracked along the grids and found their way round them into the suction zone of the traps beyond.

TABLE I. *Comparison of catches in screened and unscreened suction traps. The screened trap was surrounded on all four sides with electric grids*

	Screened trap		Unscreened trap	
	Total caught	% dead	Total caught	% dead
Grids switched ON	731	22·7	2590	7·8
Grids switched OFF	566	10·4	2531	6·5

This evaluation of the technique showed that the electrified grids could be used as directional screens in association with suction traps, provided that dead mosquitoes were excluded from the calculations. At the same time, it was evident that the grids were only 75–80% efficient in blocking the passage of mosquitoes and that the results of flight experiments should be interpreted with this finding in mind.

Unbaited catches

In planning the directional catches, it was originally intended to operate the traps simultaneously at two different levels. However, anomalous results with traps at 1 m and 2 m above the ground soon led us to abandon this type of catch. For example, during nine catching periods when the wind at 1 m averaged between 2 and 3 m/s, two-thirds of the mosquitoes in traps at 1·2 m were caught in traps facing downwind; that is, they were apparently flying upwind. Since it would appear almost impossible for mosquitoes to make headway in wind speeds of this order, we concluded that some other factor must have influenced their behaviour. The most likely explanation was that the superstructure of the fans and the steel angle supports were acting as a windbreak and that the mosquitoes were approaching in the wind shadow so created. Since the experimental technique adopted was specifically intended to eliminate such effects, it was clear that the use of elevated suction traps could not be continued. Consequently, in all the experiments reported here, the traps were set up with their mouths just above the ground and with the supporting structures sunk in pits below ground level.

Catches with the traps at ground level in the absence of baits were carried out during 64 periods, each of 1–2·5 h, on 27 nights. The results are set out in Table II. In all groups of mosquitoes, there was an overall deficit in the traps facing upwind compared with the numbers in the traps open on the downwind side. In the case of the two most abundant groups (unfed *Mansonia* and unfed *Anopheles*), this figure differs significantly from the 50% in each trap that random entry into traps would have shown. There was, however, considerable variation in the distribution of mosquitoes between the two traps during the seven weeks covering the experimental period. During the initial 19 days (catches on 11 nights), a mean of 44·7% of the total catch was taken in the traps facing upwind; during the middle 10 days (catches on 8 nights), this figure fell to 23·1%, while during the final 12 days (catches on 7 nights) it rose again to 39·9%. The 5% confidence limits for the mean catch during the middle period were 17·8–28·4%, compared with 40·6–47·8 and 30·6–49·2% for the initial and final periods, respectively.

TABLE II. *Catches of mosquitoes in traps facing upwind expressed as percentages of the total catches in traps facing upwind and downwind*

		Percentages in traps facing upwind	
	Nos. trapped	Mean	5% confidence limits
Unfed females			
Mansonia spp.	1445	39·0	33·7–44·3
Anopheles spp.	798	32·2	27·5–36·9
Banded *Culex* spp.	204	35·7	
Aedes spp.	165	41·8	
Total	2612	35·7	31·0–40·4
Gravid females (all species)	46	34·8	
Males	135	44·4	

There was no alternation in experimental design that could account for this variation. Furthermore, very similar results were obtained on 12 nights when two pairs of traps, in different pits but orientated in the same direction, were operated simultaneously. It did not appear from this that position effects were important, nor do the results appear to have been influenced by wind speed. During individual trapping periods, wind speeds at 1 m ranged from 0·6 to 3·3 m/s. Catches during 17 and 20 periods when the wind was, respectively, more and less than 1·45 m/s gave almost identical proportions of mosquitoes in traps facing upwind (34·4 and 36·2%). On the other hand, analysis of catches during periods of moonlight, defined as those when the moon was above the horizon for more than half the trapping period, showed well-marked differences. On 11 moonlit nights, the numbers in the traps facing upwind formed 27% of the total catch, compared with 41·3% on 19 moonless nights. This difference is significant ($t=3{\cdot}294$, $P<0{\cdot}01$). Inspection of the numbers caught on a nightly basis confirms this relationship with moonlight. We had planned to continue the catches through at least one more lunar cycle, but, unfortunately, torrential rains and the consequent waterlogging of the experimental area, followed by unstable wind conditions, prevented us from following up this interesting finding.

Another factor that could have influenced the results was the direction of the wind in relation to the experimental area. Since steady winds only blew from two quarters, SE–SW (6 nights) and SW–NW (19 nights), it was only possible to compare responses to these two wind directions. The mean catches in traps facing upwind for the two situations were almost identical at 36·3 and 33%. Thus, no evidence was obtained of any other heterogeneity in the physical environment, such as features of the skyline, that could have affected the flight direction of the mosquitoes.

These catches were carried out in an open site in the absence of bait. However, there was a large village, the nearest parts of which were 0·5 km to the south and south-west of the traps. We have no information on the distance downwind over which mosquitoes might detect and orientate to a source of attractant of this size. It could be argued, however, that the apparent upwind movement of the mosquitoes might have been determined by the presence of the village. Two points seem to militate against this. Firstly, that the wind was usually from the SW–NW quarter, in which direction the nearest village (a small one) was 1–1·5 km distant. Secondly, as shown in Table II, upwind flight predominated in gravid females as well as in unfed ones, and the flight pattern of the former would presumably not be influenced by olfactory stimuli coming from human settlements.

Baited catches

A small series of catches was carried out with a man as bait stationed about 3 m upwind of the traps, with the object of testing the validity of the technique. Since orientation to a warm-blooded host involves upwind flight, the majority of the mosquitoes should have been caught in the traps facing downwind.

The catches were carried out in two ways. In a first series, four baited catches lasting 1 h and four unbaited catches lasting 1 h were carried out consecutively at the same site with an interval of 15 min between catches. In a second series, of five 1-h periods, baited and unbaited catches were carried out simultaneously at two different sites, 12 m apart on a line at right angles to the axis of the wind. The two techniques gave similar results. Combining the results for all species, a total of 1729 mosquitoes was collected, and mean catches in the traps facing downwind were 85·7% of the total when baited and 74% when unbaited ($t=2{\cdot}77$, $P<0{\cdot}02$). Both sets of experiments were carried out during moonlit periods.

Discussion

The problems of flight orientation in relation to wind direction has previously been studied in West Africa, using two other techniques. Snow (1976), working in a coastal region of The Gambia, employed directional flight traps (ramp traps (Gillies, 1969)) both in the presence and absence of hosts. A possible objection to this technique is the fact that ramp traps, being made of plastic netting, create a considerable wind shadow on the downwind side, which could have affected the flight pattern of the insects. The electric grids used in the present study were free from this defect. It is of interest, therefore, that the present results are in line with Snow's finding that, in the absence of hosts, mosquitoes flying at low levels show a greater tendency to fly upwind rather than downwind. An indirect approach was used by Gillies & Wilkes (1974), who argued that, if mosquitoes were dispersing upwind, they should be partially diverted round a host by a semicircular fence set up on the downwind side, provided this was far enough away for the insects to encounter it before they detected the host. The absence of any diminution in the attack rate on the host in these experiments led the authors to the opposite conclusion, namely that a significant number of mosquitoes were approaching from the downwind side. More recent (unpublished) experiments with a much larger fence gave rather different results, and so less definite conclusions can be drawn from the original experiment than was formerly thought.

The present results show that suction traps in conjunction with electrified grids can provide information on the direction of flight of mosquitoes. The technique appears to give a general picture of flight pattern near the ground but requires further refinement if we are to obtain a more precise estimate of upwind and downwind movement. Firstly, the screening described here allows the approach of mosquitoes from any direction within an arc of 180°. In theory, this means that the traps facing upwind could have been sampling mosquitoes approaching from any angle from straight down the wind to almost at right angles to it.

Secondly, the efficiency of the electric grids as screens is less than 100%; our estimate was 75–80%. The following equations show the effect of grid efficiency on the relationship between the true proportion of mosquitoes flying upwind (a) and the proportion estimated to be flying upwind (x):

$$x=\frac{a(1-z_d)+z_d}{1+z_d+a(z_u-z_d)} \quad \text{and} \quad a=\frac{x(1+z_d)-z_d}{1-z_d-x(z_u-z_d)}$$

where z_d=proportion of downwind fliers getting through the grid and z_u=proportion of upwind fliers getting through the grid. On the assumption that $z_d=z_u=z$, the equations can be simplified to:

$$x=\frac{a(1-z)+z}{1+z} \quad \text{and} \quad a=\frac{x(1+z)-z}{1-z}$$

From these equations, it can be calculated that, if the grid efficiency is 75–80% (z=0·2–0·25), a catch of 64% in the traps facing downwind would indicate that 71–73% of the mosquitoes were actually flying upwind. The equations show that, unless there is a large disparity in the efficiency of the grids in the two directions, the true difference between the proportion flying upwind and downwind will be greater than the estimated difference.

Thirdly, there is the effect of the traps on the flight pattern one is trying to measure. With the technique described here, a major limitation is the obstruction to air flow caused by the bodies of the suction traps and their supports when these project above the ground. Studies currently in progress suggest that the electric grids themselves can be used as trapping devices for mosquitoes, in the same way as Vale (1974) used them for tsetse flies. This approach dispenses with the need for bulky traps and could provide a method for studying flight orientation at any level.

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