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The effect of high fences on the dispersal of some West African mosquitoes (Diptera: Culicidae)

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Abstract

Many West African mosquitoes fly at low levels when crossing open country. Experiments were therefore conducted in the Gambia on the effect of high fences on their dispersal. In the first experiment, a circular mosquito-proof fence 2·9 m high and with a radius of 18 m was constructed. Catches inside on human bait of *Mansonia* spp. were about 60% lower than catches outside the fence, whereas catches of *Anopheles* spp. in the two sites were not significantly different. In unbaited suction traps, catches of *Mansonia* inside the fence were significantly lower in traps 0 and 0·5 m above the ground, but not at 1 to 3 m, than in traps at similar levels outside. This suggested that, after flying over the fence, mosquitoes had not resumed normal flight levels by the time they were trapped in the centre of the circle. In a second experiment, a much larger fence was erected, 6 m high and with a radius of 65 m. Catches were conducted in experimental huts in the centre of the enclosed area and at a distance of 70 m outside it when the fence was erected and again after its removal. Catches of *Mansonia* spp. on human bait in the hut inside were 46% of the total catch in the two huts when the fence was erected and 48% after its removal; catches of *Anopheles* spp. (*A. gambiae* Giles and *A. funestus* Giles) were 43% with, and 53% without, the fence. In calf-baited light-traps, catches of *Mansonia* were 41% of the total with, and 38% without, the fence, and those of *Anopheles* 58 and 44%. Thus the presence of the 6-m fence had no significant effect on the density of mosquitoes in the centre of the enclosed area, and it is concluded that mosquitoes were flying freely over it. Due to the prevailing low winds in the area, passive transport of mosquitoes over the fence by the wind was not thought to be important.

Introduction

In dispersing over open country, many West African mosquitoes fly very close to the ground (Snow, 1975; Gillies & Wilkes, 1976). The latter authors suggested that these species might be more likely to be affected by windbreaks and vertical barriers than those, relatively few in number, that normally fly at greater heights. Bidlingmayer (1971, 1975) has shown that the flight paths of mosquitoes in Florida are strongly influenced by clumps of vegetation or other physical barriers. It is well known that mosquitoes, like many other insects, tend to accumulate in sheltered situations (*e.g.* Klassen & Hocking, 1964). The question is not often considered, however, as to how they move on from such sites. Further dispersal might be achieved either by tracking along the edge of shelter belts, or the insects might pass on over the top.

In the present paper, we describe experiments to determine which of these patterns of movement is shown by savanna mosquitoes in the Gambia. The method adopted was to erect circular, mosquito-proof fences and to compare the density of mosquitoes in the centre of the fenced area with that outside.

Methods

The experiments were carried out in two localities adjacent to the River Gambia in the rainy seasons of 1974 and 1976. The first was the area of open farmland described by Gillies & Wilkes (1976). The second site, in the same general vicinity and near the village of Wali Kunda, was an open area of grass-covered fallow, surrounded on most sides by open woodland composed of a mixture of low thorny bushes and scattered trees up to a height of 12–13 m. On one side, this was replaced by a sparse belt of bushes, which separated it from a wide expanse of seasonally-flooded rice-fields. In practical terms, this meant that the surrounding woodland presented no obstruction to the free movement of mosquitoes through it but that air-flow across the open area was to some extent reduced by the shelter of the surrounding vegetation.

In the first experiment, a circular fence was constructed of black, heavy duty polyethylene, 2·9 m high and with a radius of 18 m. Biting catches were carried out on single human baits, one sitting in the centre of the circle and one at a distance of 65 m outside it. The catchers changed places every half-hour. Suction-trap catches were carried out with 22·8-cm Vent-Axia fans mounted on steel scaffolding with the mouths of the traps at ground-level and at 0·5, 1, 1·5 and 3 m above the ground. Not more than three levels were sampled in any one experiment. Two columns of traps were set up, one in the centre of the fenced circle, the other at the same site as the biting catches outside it. Catches were run for two periods a night for 30 nights.

For fencing material in the second experiment, at Wali Kunda, we made use of Lobrene, a semi-permeable, woven polypropylene fabric, marketed for use as a protection material in agriculture. The fence was 6 m high and with a radius of 65 m (Plate IX *a*, *b*). We had some trouble in maintaining a fence of this size, with a circumference of over 400 m, particularly in repairing the damage caused by cyclonic storms. However, it remained intact long enough to complete the series of catches. The enclosed area was grass-covered, changing from almost bare earth at the start of the season to tall grass by the end. A few rhun palms and one or two tall trees remained within the fence, but there was no bushy vegetation that might have served as daytime resting sites for mosquitoes.

In the centre of this large enclosed area, an experimental hut was built, 3·7 m square, with mud walls and thatched roof. Entry for mosquitoes was provided for by a space under the eaves, kept open by double wall-plates. A similar control hut was built in an open area 70 m from the fence. Because of the distance between the two huts and possible differences in terrain, mosquito densities at the two sites could not be assumed to be equal. To assess the effect of the fence, therefore, series of catches were carried out simultaneously in the two huts, first of all with the fence in place and again after its removal. In this way, the ratio of mosquito densities in the two huts was measured under the two conditions.

Densities in the experimental huts were measured by two different methods. Human-bait catches were made by single catchers sitting inside the two huts for two hours each night between 21.00 h and midnight. The catchers were alternated between the two huts on successive nights. When the biting catch was completed, a man-sized calf was introduced into each hut. The calves were tied up inside mosquito-proof stalls placed along one wall of the huts. The stalls were of wood up to a height of about 90 cm, the upper 60 cm of the sides and roof being of mosquito netting. The calves were regularly alternated between the two huts. A Monks Wood light-trap, Service (1970, 1976), was suspended just below the eaves in the opposite corner of the hut and left switched on until sunrise next morning. Thus, each night's catch normally consisted of a 2-h man-biting catch and a 6–7-h calf-baited light-trap catch. On some occasions, only one type of catch was carried out.

The light source in the Monks Wood trap is a 23-cm 6-W fluorescent tube. This gives a relatively bright light, and at first we found that catches in the traps were rather poor. The fluorescent tube was therefore progressively shielded with aluminium foil until only the bottom 2·5 cm of the tube, just above the fan, was exposed. With this greatly reduced light source, good catches of house-entering mosquitoes were made, and the modification was adopted for all routine catches.

Catches were also made to assess the effect of the high fence on the density of mosquitoes approaching it from the outside. Three columns of suction traps were set up adjacent to the fence in a section cleared of low bushes and with the grass cut short. The columns were spaced at approximately 0·25, 1 and 13 m from the outer side of the fence, and traps were operated at each site at levels of 0·5, 1 and 5 m above the ground. The innermost column was thus close up against the fence, while the outer column was at a distance about equal to twice the height of the fence away from it. Traps were operated from 19.30 to 23.00 h for 18 nights when the fence was standing and for 12 nights after its removal. This enabled the density of mosquitoes at the site of the fence to be compared with a point 13 m away, both in the presence and the absence of the fence.

Results

Mosquito fauna

Both African species of the subgenus *Mansonioides* of *Mansonia*, *M. africana* (Theobald) and *M. uniformis* (Theobald), were present in the catches, the former being the more abundant, particularly in the early part of the season. In the hut catches, few *Anopheles* other than *A. gambiae* Giles and *A. funestus* Giles were caught. On the basis of earlier identifications in the district, *A. gambiae s. s.* was assumed to be the only member of the complex present. In the outdoor biting catches, the species trapped comprised *A. pharoensis* Theobald, *A. gambiae*, *A. ziemanni* Grünberg, *A. funestus* and *A. squamosus* Theobald, in that order of abundance. The main species of *Aedes* trapped in these catches were *Ae. argenteopunctatus* (Theobald), *Ae. sudanensis* (Theobald), *Ae. dalzieli* (Theobald), *Ae. minutus* (Theobald) and *Ae. ochraceus* (Theobald), together with small numbers of other species.

Catches in relation to 2·9-m fence

From the results of 22 catches of 1 h on human bait shown in Table I, it will be seen that densities of *Mansonia* and *Aedes* spp. were significantly lower in the centre of the enclosed area compared with the open ground outside. On the other hand, the density of *Anopheles* spp. was virtually the same at the two sites.

TABLE I. *Results of 22 human-bait catches, expressed as geometric mean (M_w) catch per 1-h period, outside and at the centre of the fenced-in circle (2·9-m fence)*

	Total nos.	Mean catch	
		Outside fence	Inside fence
Mansonia spp.	1939	57·2	23·2**
Anopheles spp.	383	6·9	7·0
Aedes spp.	168	3·4	0·9**

**Difference significant, $P < 0·01$

The densities of *Mansonia* spp. in unbaited suction traps at six different heights in the centre of the circle and at the same levels outside it are shown in Table II.

TABLE II. *Suction-trap catches of* Mansonia *spp. at different heights, expressed as geometric mean* (M_W) *catch per night, outside and at the centre of the fenced-in circle (2·9-m fence)*

Height of trap (m)	No. of catches	Total nos.	Mean catch	
			Outside fence	Inside fence
0	9	4648	296·9	89·0**
0·5	13	814	32·8	23·6*
1	19	1294	25·7	21·4
1·5	13	281	9·4	10·1
2	7	452	30·4	24·4
3	7	301	18·6	21·4

**Difference significant, $P < 0·01$
*Difference significant, $P < 0·05$

Catches at ground level inside the fence were much smaller than those outside; at 0·5 m, the difference was less but still significant. Above this level, the difference was even smaller, and the catch at 3 m inside the fence was slightly higher than outside. Further evidence for raised densities at higher levels comes from a short series of biting catches on man made the previous year with a fence of the same dimensions but constructed of plastic mosquito netting instead of polyethylene. Seven 1-h catches were made at 1 m inside and outside the fence, followed after an interval of 10 min by similar catches on scaffolding towers at 3 m. At the 1-m level, the geometric mean catches of *Mansonia* inside and outside the fence were 51·2 and 82·4, respectively, which are significantly different ($P < 0·05$). At 3 m, the mean catches were 47·5 inside and 37·5 outside, which are not significantly different, but taken in conjunction with the difference at the two levels with suction traps, it appears that the vertical stratification of mosquitoes inside the centre of the fenced area was different from that outside.

TABLE III. *The mean catch per night in the fenced hut expressed as a percentage of the combined mean catch in fenced and control huts (6-m fence)*

Species	Fence present (20 catches) %	Mean catch 5% conf. limits	Total nos.	Fence absent (14 catches) %	Mean catch 5% conf. limits	Total nos.
Biting catches						
Mansonia spp.	46·0	42·3–49·7	5553	47·7	44·3–51·1	4744
A. gambiae + *A. funestus*	42·9	38·9–46·8	1009	53·0	45·6–60·3	1101
Light-trap catches	(20 catches)			(13 catches)		
Mansonia spp.	40·9	37·5–44·3	9305	38·3	28·6–48·0	5299
A. gambiae + *A. funestus*	57·4	55·0–59·9	1322	43·7	36·3–51·2	217

The radius of the circle was approximately six times the height of the fence. To increase this ratio and, at the same time, to test the responses of mosquitoes to a higher barrier, a much larger circular fence was constructed, 6 m high and with a radius of 65 m. It was hoped in this way to avoid the possibility of distorted vertical stratification of mosquitoes in the centre of the circle.

Catches in relation to 6-m fence

The results of human-bait catches and of calf-baited light-trap catches in the experimental hut in the centre of the fenced area and in the control hut at a distance of 70 m outside it are shown in Table III. Comparing the left- and right-hand sides of the table, it will be seen that the numbers of mosquitoes in the fenced hut, expressed as the percentage of the total in both huts, before and after the removal of the fence, were not significantly different. In other words, the presence of the fence appeared to have no effect on the relative numbers of *Mansonia* or of *Anopheles gambiae* and *A. funestus* caught in the two experimental huts.

The results of catches in suction traps operated on the outside of the fence are shown in Table IV. The relative change in catch in each trap, *i.e.*, whether it increased or decreased, when the fence was present is shown in Table V. It will be seen that

TABLE IV. *Distribution of catch in suction traps outside the 6-m fence according to height and distance, expressed as the percentage of the total catch in all suction traps*

Height of traps (m)	*Mansonia* spp. Distance from fence (m) 0·25	1	13	Total nos.	*C. poicilipes* Distance from fence (m) 0·25	1	13	Total nos.
0·5	16·1* / 11·8	19·2 / 14·0	12·7 / 18·8	7338 / 1011	1·5 / 3·1	2·6 / 2·4	7·1 / 3·9	1160 / 610
1	20·6 / 10·4	13·8 / 11·5	5·6 / 16·2		2·3 / 4·0	2·9 / 3·9	5·7 / 4·0	
5	4·0 / 5·7	3·9 / 4·5	4·0 / 7·0		9·6 / 23·4	20·2 / 24·7	48·1 / 30·3	

*The upper percentage figure in each pair refers to the catch when the fence was present (18 catches), the lower figure when the fence was absent (12 catches).

TABLE V. *Change (positive or negative) in catches in nine suction traps when the 6-m fence was present compared with when it was absent*

Height of traps (m)	*Mansonia* spp. Distance from fence (m) 0·25	1	13	*C. poicilipes* Distance from fence (m) 0·25	1	13
0·5	+**	+*	−**	−*	+	+**
1	+**	+	−**	−*	−	+
5	−	−	−**	−**	−	+**

*Change outside the confidence limits at the 5% level.
**Change outside the confidence limits at the 1% level.

there was a striking difference in the effect of the fence on the two types of mosquito, which is related to their vertical distribution. Thus, catches of the low-flying *Mansonia* spp. in the low-level traps close to the fence were significantly greater before its removal than afterwards, while the reverse occurred in traps 13 m from the fence. These findings are consistent with the idea that mosquitoes were accumulating at low levels close to the fence, thus causing a relative fall in density in both the higher and the more distant traps. On the other hand, the picture given by the high-flying species *Culex poicilipes* (Theobald) is exactly the opposite. Catches near the fence were much smaller before its removal, especially at the 5-m level, while at the distant site catches were much greater before it was removed.

Discussion

These experiments were designed to answer the fairly simple question of whether dispersing mosquitoes fly horizontally round vertical barriers or whether they change level and fly over the top. The results were clear-cut. In the type of farmland and open woodland that surrounded the experimental area, a circular fence 6 m high had no effect on the density of mosquitoes in the centre of the enclosed area. The mosquitoes must, therefore, have entered the area over the top of the fence before detecting the host and entering the experimental huts. In the light of these findings, it seems clear that the reduction in biting activity of *Mansonia* in the centre of the smaller circle surrounded by the 2·9-m fence must have been related in some way to the dimensions of the fence. Although our earlier studies (Gillies & Wilkes, 1972) had indicated that mosquitoes were not detecting man-sized calves from a greater distance than 14–18 m, it is possible that this was an underestimate. If this were so, the responses of mosquitoes to the fence could have been affected by the presence of host-stimuli penetrating beyond the fence. Furthermore, evidence from the use of suction traps showed clearly that the vertical distribution of *Mansonia* at the centre of the smaller circle was different from that outside. It seems likely, therefore, that the reduction in biting rate at ground level inside the fence could have resulted from the fact that mosquitoes flying over the fence had not resumed their previous flight levels by the time they reached the centre of the circle. A proportion of them would then pass above the bait without detecting his presence and so avoid capture. If this were so, it follows that the behaviour of *Anopheles* differed from that of *Mansonia*, in that the *Anopheles* were achieving their previous flight level more quickly than *Mansonia* and so were attacking the enclosed bait in unreduced numbers.

What we were studying in these experiments was the end-result of the mosquitoes' responses to contact with the fence, rather than the responses themselves. This was deliberate, since we were interested in the possibility of manipulating the flight paths of mosquitoes in a way that might have some bearing on methods of control. However, from the use of suction traps, evidence was obtained that *Mansonia* was accumulating at low levels close to the fence. This could have resulted from mosquitoes flying laterally along the fence before changing level and flying upwards or, alternatively, from repeated to-and-fro movements in any of three different planes. It is evident, from the densities of mosquitoes inside the circle, that this phase of activity was of limited duration and that sooner or later they worked their way up the fence and over the top. This finding suggests that mosquitoes were responding to close contact, either visual or tactile, with the fence rather than to the image of the skyline perceived from a distance. In the latter case, catches in the traps adjacent to and just below the top of the fence would have shown a decrease relative to the trap at the same level but distant from the fence, which was the case for *C. poicilipes* but not for *Mansonia*. We conclude that *Mansonia* continued their normal low-level flight until close to the fence and, after some delay, flew up and over it.

The reduction in numbers of *C. poicilipes* in traps near the fence could be explained in terms of quite different responses, depending on whether mosquitoes were approaching the fence from outside or inside the circle. In the former case, the findings would conform to the idea of response to the skyline. If they were approaching from inside the circle, *i.e.*, from the opposite side of the fence to the traps, unless the mosquitoes dropped down to lower levels immediately after flying over the fence, catches would be reduced in the adjacent traps regardless of the responses of the mosquitoes as they approached the fence. Since we have no information on the direction of approach, no conclusion can be drawn about the mechanisms of the response of this mosquito to physical barriers.

Bidlingmayer (1975) found that suction traps sunk in the top of a barrier approximately 2 m high set up in the field in Florida, caught more mosquitoes of most groups than when the barriers were absent. His findings, like ours, show that many mosquitoes were responding by flying over the barrier; but, since in his experiments it was possible that some of them tracked round it, an estimate cannot be made of the proportion behaving in one way rather than in another. He makes the interesting point that woodland species, being accustomed to an environment without horizons, might be less responsive to skyline factors than field species. His results support the theory. Our findings with African *Mansonia*, however, suggest that, in this group of field species, horizon factors were not important.

Insects can surmount physical barriers by passive transport on the wind, or by their own active movements. The accumulation of pasture insects behind fences and windbreaks in England was shown by Lewis (1966) and Lewis & Dibley (1970) to be dependent on both processes. Similar wind-mediated effects could operate with the type of circular barrier that we used. If the wind was strong enough, mosquitoes would be carried over the fence on the upwind section, from whence they could disperse freely downwind towards the bait in the centre of the enclosed area. The fence would thus represent no barrier to the movement of insects, and biting densities inside the enclosure, other things being equal, would approximate to those outside. With the 2·9-m fence, which was made of impermeable material, wind effects could well have been important. The site was very open, and wind speeds at a height of 1·2 m during the course of the experiments were 1·4 and 1·25 m/s. Moreover, wind speed in the centre of the circle at 1·2 m was lower by a factor of 0·43 than that at the same level in the open. On the other hand, the 6-m fence, which was made of semi-permeable material, was set up in an open wooded area, which presented considerable shelter from the wind. Although the size of the cleared area inside the fence was great enough for the centre to be free of any windbreak effect from the fence itself, overall wind speeds across the fence were very light. Owing to instrument failure, records of the wind were not kept during the main experiment, but immediately prior to this, at a time of year when winds are normally high, mean wind speed in the centre of the cleared area was 0·95 m/s. At the same site, later in the same season of the previous year, the figure was 0·21 m/s. At the perimeter, shelter effects would have been greater still, and under these conditions passive transport of insects over the fence would appear to have been of minor importance.

In an earlier paper (Gillies & Wilkes, 1974), we showed that, while a semi-circular fence of radius 18 m on the downwind side of a bait had no effect on biting density, completing the screened circle led to a reduction in the biting rate of *Mansonia* of about 30%. We concluded that, in the first experiment, a considerable number of mosquitoes must have been approaching the bait from the upwind (unscreened) side and that downwind flights by mosquitoes formed an important part of their host-seeking strategy. However, in view of the readiness with which mosquitoes surmounted the 6-m-high fence in the present experiments, it now seems clear that the reduction achieved with the small fence must be attributed to its dimensions rather than to the direction of approach of the mosquitoes. The conclusions on the importance of downwind flight from the earlier experiment cannot therefore be sustained.

The general picture given by all these experiments is of mosquitoes dispersing rather freely over open country and of physical barriers of moderate height—at least 6 m—having no more than a retarding effect on their movement. One can predict from this that, when they encounter natural features such as tall grass, regenerating bush or tree belts that cannot easily be penetrated, they would tend to modify their level of flight in order to pass over the obstruction. Normal flight levels would be resumed on the other side. This would imply that, although physical barriers might cause temporary deviation in their track, the overall direction of flight was determined by the wind rather than by topographical features, some evidence for which was presented by Gillies, Jones & Wilkes (1978).

The present experiments were also intended to answer the question of whether physical barriers could be used to influence the flight paths of mosquitoes. Under West

African conditions, barriers could be shelter belts of, for example, mango trees in combination with some sort of fencing. The results from the use of artificial barriers, however, give no encouragement to the idea that tree belts would be effective for this purpose, even though they might grow to considerably greater heights than the fences we tested.

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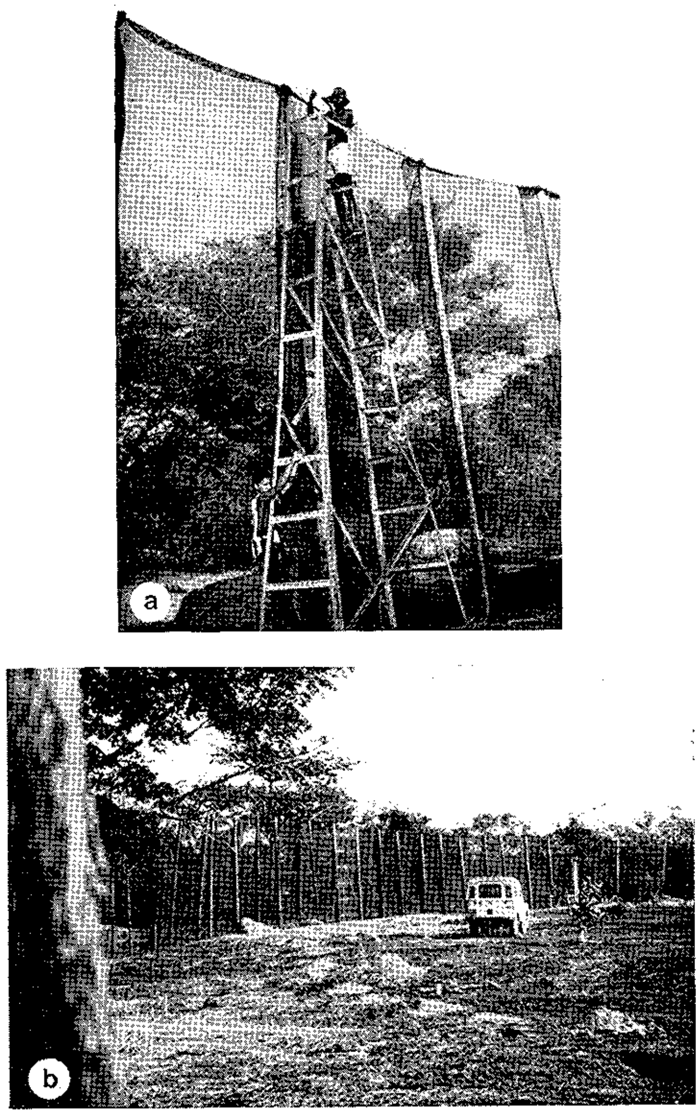

Sections of the 6-m fence under construction.