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Field Experiments on the Behaviour of Malaria Vectors in an Unsprayed Hut and in a Hut Sprayed with DDT in Northern Nigeria

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Investigations on the behaviour of malaria vectors in DDT-sprayed houses are of special interest in malaria control campaigns. In the Northern Region of Nigeria the behaviour of the local vectors was studied by means of experimental huts fitted with exit window-traps. The results obtained show a marked reduction in the number of mosquitos entering the sprayed hut and a depression of the biting rate. The most striking observation is the large number of A. gambiae *and of* A. funestus *that left the sprayed hut and the considerable proportion that escaped unharmed. Both figures show a very marked increase in subsequent months after spraying, indicating a rapid loss of the lethal action of the DDT residue along with a long-lasting irritant effect. It is concluded that under the particular local conditions the application of 1.9 g/m² DDT twice a year may not be sufficient to interrupt malaria transmission in the Northern Region of Nigeria.*

INTRODUCTION

House-spraying with residual insecticides against adult anophelines is an effective and widely used antimalaria measure today. In the mass control campaign in Northern Nigeria routine house-spraying has been carried out continuously since 1954.[2] At first DDT, dieldrin and γ-BHC were applied against the local malaria vectors *Anopheles gambiae* Giles and *A. funestus* Giles. After insecticide resistance developed in *A. gambiae* to dieldrin (Elliott & Ramakrishna, 1956; Davidson, 1956a) and cross-resistance to γ-BHC (Davidson, 1956b), all the house-spraying had to be switched over to DDT. Since October 1957 all the houses in the area have been treated with this insecticide, which is applied now at the rate of 1.9 g/m² technical DDT water-dispersible powder twice a year; as a result there has been an enormous drop in the numbers of *A. gambiae* and *A. funestus* resting indoors. This drop was followed by a marked decrease in the parasite index in the human population. However, the interruption of malaria transmission has not yet been achieved. The vector densities in the huts are still low, the mosquitos are still susceptible to DDT, and there are no indications of secondary vectors so far. This suggests that a number of vectors escape the lethal effect of the DDT and that the proportion is large enough to maintain the life-cycle of the malaria parasites. Various reasons, e.g., poor spraying, presence of unsprayed huts, outdoor resting of vectors, etc., could account for the failure to interrupt transmission. Investigations on the behaviour of the local vectors in treated huts were indicated, among others. In particular it appeared that observations to determine whether the same number of mosquitos enter sprayed houses as unsprayed ones and the fate of those specimens which enter treated houses would be of interest. Experimental investigations designed to throw some light on these questions were started in Northern Nigeria in August 1958 and continued over 15 months. Preliminary results obtained with *A. funestus* have been published elsewhere (Kuhlow, 1959). The present paper deals mainly with observations on *A. gambiae*.

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[2] Bruce-Chwatt, L. J., Archibald, H. M. & Haworth, J. (1958) Fourth Annual Report on the Western Sokoto Pillot Project (Mimeographed document).

LOCALITY AND TECHNIQUE

Locality

In order to obtain sufficient numbers of mosquitos the experiments were carried out in the unsprayed zone. Therefore—it should be kept in mind—the results obtained do not necessarily reflect the conditions in the neighbouring sprayed area.

The village of Natsini in western Sokoto was selected for the investigations because of its high mosquito density and because it is accessible by car the year round. Natsini is situated in the Sudan savannah zone of Northern Nigeria. The annual rainfall is about 760 mm, of which 90% falls in the rainy season (June to September). The daily temperatures vary considerably. In the winter months when the cool and dry harmattan wind blows from the Sahara, the relative humidity decreases to 10% or less in the afternoon, and at night the temperature at Natsini sometimes drops to 9°C. Soon after the harmattan stops the temperature rises sharply; daily maximum temperatures during March, April and May are 40°-45°C or even more.

Like most of the people in Sokoto Province the villagers of Natsini belong to the Hausa ethnic group. The families live in compounds consisting normally of two or more huts enclosed by a high fence of straw mats or mud. Only infants sleep in the hut with their mothers; older children have their own huts.

Technique

The behaviour of the local malaria vectors in sprayed and unsprayed houses is best studied by means of experimental huts fitted with exit window-traps. This technique was introduced by Muirhead-Thomson (1947) and has proved to give a reliable estimate of the fate of mosquitos entering sprayed houses. Our huts and methods have been described before, but some repetition may be appropriate.

Experimental huts. In order to obtain results under conditions as similar to the normal local ones as possible, no special huts were built but ordinary inhabited huts were used for the experiments. The villagers let us have two suitable huts in which older boys slept; these were accessible to us at all times. The two huts were of the local round type, 300 cm and 340 cm in diameter, with walls 145 cm and 160 cm high, built of mud only, and conical thatched roofs 310 cm and 320 cm high at the centre. The only openings in the huts were the entrance and small spaces, 1-3 cm wide, between the top of the wall and the roof. For the window-traps an opening 30×30 cm facing south-east was made in the wall of each house. One of the huts (A) was left unsprayed for control, the other one (B) was sprayed with DDT. Both huts were free of ants.

Window-traps. The traps constructed were similar to those described by Muirhead-Thomson. A wooden box frame 30 cm deep was covered with green mosquito gauze and fitted to the window opening. The entrance end of the trap formed a funnel supported by a wire frame and ending in an opening 1.5 cm wide about 3 cm from the outer end, thus acting as a one-way valve. The mosquitos caught could be taken out through a sleeve. Strips of plywood 15 cm wide kept the trap in position in the window opening and covered the small space between the wall and the trap. The traps were protected against rain by the overhanging roof.

In the initial stage of the work contamination of the traps became obvious from high mortality among mosquitos obtained from the trap of the control hut. For this reason the figures obtained in that period were discarded when the survival rate was estimated. After the traps had been thoroughly cleaned with acetone the control mortality fell to low levels and remained low for the rest of the experiments.

Methods of collection. Both experimental huts were used in the same way and all the work was done under supervision. The huts were visited five times per month, usually two or three nights in succession. Before the beginning of each catching period the huts were sprayed with a commercial preparation of pyrethrum in the early morning in order to clear them of resting mosquitos. At dusk, the window-traps were fixed and a large white sheet spread on the floor, properly stretched to the wall. At about 8 p.m. equal numbers of people, usually five, entered each hut. They were instructed not to cover their legs or kill biting mosquitos.

The doorway was closed by a dark-blue sheet at 10 p.m., after which time the eaves provided the only means of entry for mosquitos. At sunrise the floor-sheets were folded loosely and taken out and the dead mosquitos were collected. Then the traps were removed, the window openings closed, another sheet spread on the floor, the huts sprayed and the killed mosquitos picked up from the spray-sheet. The dead mosquitos in the traps were taken out and the living specimens transferred into paper cups covered with mosquito netting and provided with cotton wool soaked in sugar solution; they were kept

in another suitable hut for a further 24 hours. At the end of this period the number of survivors and the number that had died were recorded. The abdominal condition of all the anophelines obtained was noted. Males caught are not included in the tables.

Spraying. Hut B was sprayed for the first time on 8 August 1958 in the same way as for the routine house-sprayings in the mass control campaign. With a Hudson X-Pert compression sprayer and a pump charge of 16 ounces (454 g) technical DDT water-dispersible powder, the total inner surface of the hut was treated at a rate of 1.9 g/m² DDT (=1.4 g/*p,p'*-isomer). However, entomological and chemical findings soon indicated that the insecticide deposit inside the hut was not sufficient. For this reason the hut was resprayed on 12 September 1958 with a strong dose of 3.8 g/m² DDT. The next two sprayings of the hut with 1.9 g/m² DDT were carried out at six-month intervals, on 4 March 1959 and 2 September 1959. The insecticide deposit in the hut was checked at intervals by the Alessandrini method. The results have been published elsewhere (Kuhlow, 1959).

RESULTS

General observations

The seasonal abundance of *A. gambiae* and *A. funestus* varied considerably. The average densities of the two species per hut per day (females only), obtained from routine spray-catches during the period the experiments were carried out, are given in Table 1. In the daytime most of the mosquitos rested on the upper wall and on the roof, where they were less disturbed by the inhabitants. In the morning, when people cooked their meal indoors and the upper part of the hut was full of smoke, the mosquitos descended temporarily to the lower part of the wall but rarely left the hut.

Other anopheline mosquitos found resting in huts were, quite frequently, *A. pharoensis*; more rarely and for a limited season, *A. wellcomei*, *A. flavicosta*, *A. rufipes*, *A. coustani*, *A. squamosus*, and *A. nili*.

Pre-experimental spray-catches in the huts selected for the behaviour investigations were carried out monthly. From March to August 1958 we obtained from hut A: 8, 39, 15, 1, 818 and 537 female *A. gambiae*; from hut B: 6, 18, 10, 6, 613 and 637. This indicates that both huts were suitable as resting places for *A. gambiae*. They were also suitable for *A. funestus*, as was shown earlier.

TABLE 1

AVERAGE DENSITY OF *A. GAMBIAE* AND *A. FUNESTUS* PER HUT PER DAY AT NATSINI (FEMALES ONLY)

Date	*A. gambiae*	*A. funestus*
1958		
August	464	52
September	343	22
October	29	35
November	32	127
December	43	118
1959		
January	4	78
February	2	126
March	2	167
April	20	56
May	44	11
June	28	7
July	308	2
August	878	12
September	550	130
October	46	43

Night catches on human bait were carried out as routine indoors and outdoors and continued from dusk to sunrise. The results obtained showed that the main biting activity of *A. funestus* was between 10 p.m. and 1 a.m. *A. gambiae* fed predominantly after midnight, between 1 a.m. and 4 a.m., but continued to bite up to sunrise. The only other anopheline caught biting man readily was *A. pharoensis*. Its main activity was from dusk to midnight.

The gonotrophic cycle in *A. gambiae* was found to be two days. Specimens caught were recorded as " fed " (when the blood meal had been taken in the previous night), as " gravid " (when it had been taken the night before that), and as " unfed ".

Behaviour in the unsprayed hut A

The *A. gambiae* obtained from hut A and its trap, consolidated for each month after the preceding spraying of hut B, are shown in Table 2. The abdominal condition of the mosquitos caught is recorded in Table 4.

A total of 8736 *A. gambiae* entered hut A during the time under observation. More than 95% of them

TABLE 2

CATCHES OF *A. GAMBIAE* FROM UNSPRAYED HUT A

	Number of months after preceding spraying of hut B																	Total catch
	1 (Aug.) 1958		1 (Sept.)	2 (Oct.)	3 (Nov.)	4 (Dec.)	5 (Jan.) 1959	6 (Feb.)		1 (March)	2 (April)	3 (May)	4 (June)	5 (July)	6 (Aug.)		1 (Sept.)	2 (Oct.)	
Number entering hut	417 (100 %)		313 (100 %)	16 (100 %)	20 (100 %)	23 (100 %)	14 (100 %)	2 (100 %)		9 (100 %)	8 (100 %)	58 (100%)	40 (100 %)	288 (100 %)	2 002 (100 %)		5 441 (100 %)	85 (100 %)	8 736 (100 %)
Dead on floor-sheet	7 (2 %)		3 (1 %)	0	0	2 (9 %)	1 (7 %)	0		0	0	0	0	0	9 (1 %)		21 (<1 %)	0	43 (0.5 %)
Alive in hut	270 (65 %)		250 (80 %)	8 (50 %)	14 (70 %)	15 (65 %)	10 (71 %)	1 (50 %)		5 (56 %)	8 (100 %)	51 (88 %)	38 (95 %)	264 (92 %)	1 803 (90 %)		4 762 (88 %)	77 (91 %)	7 576 (87 %)
In trap	140 (33 %)		60 (19 %)	8 (50 %)	6 (30 %)	6 (26 %)	3 (22 %)	1 (50 %)		4 (44 %)	0	7 (12 %)	2 (5 %)	24 (8 %)	190 (9 %)		658 (12 %)	8 (9 %)	1 117 (13 %)

TABLE 3

CATCHES OF *A. GAMBIAE* FROM SPRAYED HUT B

	Number of months after preceding spraying																	Total catch
	1 (Aug.) 1958		1 (Sept.)	2 (Oct.)	3 (Nov.)	4 (Dec.)	5 (Janv.) 1959	6 (Feb.)		1 (March)	2 (April)	3 (May)	4 (June)	5 (July)	6 (Aug.)		1 (Sept.)	2 (Oct.)	
Number entering hut	446 (100 %)	Resprayed	346 (100 %)	18 (100 %)	15 (100 %)	17 (100 %)	0	0	Resprayed	1 (100%)	3 (100 %)	10 (100 %)	13 (100 %)	193 (100 %)	1 144 (100 %)	Resprayed	3 292 (100 %)	44 (100 %)	5 542 (100 %)
Dead on floor-sheet	117 (26 %)		148 (43 %)	7 (39 %)	8 (53 %)	7 (41 %)	0	0		0	0	2 (20 %)	1 (8 %)	13 (7 %)	202 (18 %)		1 908 (58 %)	15 (34 %)	2 428 (44 %)
Alive in hut	24 (5 %)		4 (1 %)	1 (6 %)	0	3 (18 %)	0	0		0	0	2 (20 %)	1 (8 %)	18 (9 %)	58 (5 %)		46 (1 %)	1 (2 %)	158 (3 %)
In trap	305 (68 %)		194 (56 %)	10 (56 %)	7 (47 %)	7 (41 %)	0	0		1 (100 %)	3 (100 %)	6 (60 %)	11 (84 %)	162 (84 %)	884 (77 %)		1 338 (41 %)	28 (64 %)	2 956 (53 %)

were caught during the rainy season July-September. The very high catches in August and September 1959 are due to prolific breeding following unusually heavy rains in July and August in that year. However, the figures are smaller than the number obtained by spray-catches from normal huts. In the latter the mosquitos also have the opportunity of entering through the entrance, which is usually open or closed only by a mat, leaving plenty of space for entering.

There were very few mosquitos dead on the floor-sheet. They were obviously squashed by the sleepers, who were worried not only by anophelines but also by culicines, bedbugs, body-lice and *Auchmeromyia* larvae.

Most of the *A. gambiae* entering the unsprayed hut remained resting inside after feeding on the occupants. In the wet season the catch consisted of 11% unfed, 85% fed, and 4% gravid females. In the dry season the specimens caught were 3% unfed, 73% fed and 24% gravid. In the wet season males made up 9% of the total catch; in the dry season, 1.5%.

A small proportion of *A. gambiae* entering the hut left it the same night. Most of them were unfed. When the trap was checked in the morning, an average of 3% were dead, all unfed specimens. During the 24-hour period the mortality increased to a total of 9%, of which 83% were unfed females. Among the males, 55% left the hut at dawn. While it may appear strange at first sight that the gravid females in the trap formed such a small proportion of the total gravid catch and of the total trap-catch, this is really an expected result in view of the spray-catches made on the days before the trap was operated. Those spray-catches evidently eliminated most of the gravid females which would have reached the trap on the succeeding nights.

For *A. funestus* the total catch obtained from the unsprayed hut in 15 months was 1547 specimens:

TABLE 4

ABDOMINAL CONDITION OF *A. GAMBIAE* AND *A. FUNESTUS* FROM BOTH EXPERIMENTAL HUTS

	A. gambiae				*A. funestus*			
	Unfed	Fed	Gravid	Total	Unfed	Fed	Gravid	Total
				Unsprayed hut A				
Total catch	928 (11 %)	7 377 (84 %)	431 (5 %)	8 736 (100 %)	339 (22 %)	1 021 (66 %)	187 (12 %)	1 547 (100 %)
Dead on floor-sheet	10 (<1 %)	32 (<1 %)	1 (<1 %)	43 (<1 %)	2 (<1 %)	11 (<1 %)	3 (<1 %)	16 (1 %)
Alive in hut	97 (1 %)	7 102 (81 %)	377 (4 %)	7 576 (87 %)	21 (1 %)	728 (47 %)	123 (8 %)	872 (56 %)
In trap	821 (9 %)	243 (3 %)	53 (1 %)	1 117 (13 %)	316 (20 %)	282 (18 %)	61 (4 %)	659 (42 %)
				Sprayed hut B				
Total catch	1 310 (24 %)	4 148 (75 %)	84 (1 %)	5 542 (100 %)	165 (34 %)	285 (59 %)	33 (7 %)	483 (100 %)
Dead on floor-sheet	133 (2 %)	2 292 (41 %)	3 (<1 %)	2 428 (44 %)	16 (3 %)	123 (25 %)	2 (<1 %)	141 (29 %)
Alive in hut	11 (<1 %)	140 (3 %)	7 (<1 %)	158 (3 %)	3 (1 %)	9 (2 %)	8 (2 %)	20 (5 %)
In trap	1 166 (21 %)	1 716 (31 %)	74 (1 %)	2 956 (53 %)	146 (30 %)	153 (32 %)	23 (5 %)	322 (67 %)

16 mosquitos (1%) were collected dead from the floor-sheet, 872 (56%) were found alive in the hut, and 659 (43%) were obtained from the window-trap.

Behaviour in the sprayed hut B

The behaviour of the mosquitos in hut B was watched during the application of the first spray. They immediately showed signs of intense irritation or repulsion. In the course of the next hour almost all left the hut.

The *A. gambiae* obtained from hut B and its trap are recorded in Table 3; their abdominal condition is shown in Table 4. The total of *A. gambiae* collected in hut B was only two-thirds of that entering hut A.

A considerable number of *A. gambiae* that entered the hut were killed inside by the action of the DDT. Nearly all of them had had a blood meal before. Only a small number of *A. gambiae* remained alive in the hut and were obtained by spray-catches in the early morning; they might have entered not long before or have rested on untreated household effects.

The most striking feature of the results is the considerable number of mosquitos that left the sprayed hut and the high proportion that escaped unharmed.

TABLE 5

MORTALITY OF *A. GAMBIAE* AND *A. FUNESTUS* FROM THE SPRAYED HUT [a]

	A. gambiae		*A. funestus*	
	Months after previous spraying			
	1-3	4-6	1-3	4-6
Total catch	3 301 (100 %)	1 273 (100 %)	108 (100 %)	27 (100 %)
Dead inside hut	1 925 (58 %)	216 (17 %)	49 (45 %)	5 (19 %)
Dead in window-trap	548 (17 %)	43 (3 %)	21 (19 %)	3 (11 %)
Died in 24-hour period	21 (< 1 %)	7 (< 1 %)	9 (8 %)	0
Total dead after 24 hours	2 494 (76 %)	266 (21 %)	79 (73 %)	8 (30 %)

[a] The catch obtained during the period when high control mortality indicated contamination of traps has been excluded from the mortality calculations; also mosquitos caught alive resting in the hut, since it remains uncertain whether these would have died during the 24-hour period.

TABLE 6

OTHER ANOPHELINE MOSQUITOS OBTAINED FROM THE EXPERIMENTAL HUTS

	A. coustani	*A. flavicosta*	*A. nili*	*A. pharoensis*	*A. ruflpes*	*A. squamosus*	*A. wellcomei*
Unsprayed hut A							
Total catch	11	14	1	328	16	4	18
Dead on floor-sheet	0	0	0	7	0	0	0
Alive in hut	0	13	1	113	14	0	1
Total in trap	11	1	0	208	2	4	17
Dead after 24 hours in trap	0	0	0	11	0	1	1
Sprayed hut B							
Total catch	8	19	2	874	8	8	35
Dead on floor-sheet	0	9	1	249	1	1	11
Alive in hut	0	4	0	5	3	0	0
Total in trap	8	6	1	620	4	7	24
Dead after 24 hours in trap	8	5	1	128	1	3	12

In the first three months after treatment 45% of the *A. gambiae* entering the hut left it the same night. This proportion increased in the next three months to 78%.

The average mortality after 24 hours during the first three months after application of the DDT was 76% (Table 5). However, during the following three months up to the next spraying the 24-hour mortality was only 21%. This shows clearly that the lethal effect of the DDT had decreased markedly. The results indicate that the DDT prevented some *A. gambiae* from feeding, since the unfed proportion of the total catch in hut B was 24%, compared with only 11% in hut A. It is also significant that in the sprayed hut only about one in ten of the unfed *A. gambiae* were found dead on the floor-sheets, whereas the proportion of the blood-fed catch found on the floor-sheets was more than half.

For *A. funestus* the total catch obtained from the sprayed hut in the course of 15 months was 483 specimens: 141 mosquitos (29%) were obtained dead from the floor-sheet, 20 (4%) were found alive in the hut, and 322 (67%) were collected from the window-trap. The average proportion of *A. funestus* that left the hut in the first three months after spraying was 52%; this increased in the following three months to 78%. The 24-hour mortality for *A. funestus* during the first three months after spraying was 73% and dropped during the next three months to 30%.

Observations on other anophelines

Apart from *A. gambiae* and *A. funestus*, seven other anopheline species were obtained from the experimental huts. The results are consolidated and shown in Table 6. The figures for *A. coustani*, *A. flavicosta*, *A. nili*, *A rufipes*, *A. squamosus*, and *A. wellcomei* are too small for any conclusions. Only *A. pharoensis* was caught in significant numbers. The most striking feature of the results is the high catch in the sprayed hut, which is 266% of that in the unsprayed hut. Unfortunately, the pre-experimental figures for *A. pharoensis*, obtained in a season of low density of this species, are too small to show whether both huts were equally attractive as resting places, so no conclusion can be drawn from this observation. As a mainly exophilic species, only one-third of the *A. pharoensis* entering hut A remained inside; the other two-thirds left at dawn. Nevertheless the over-all mortality among 874 *A. pharoensis* collected during six months from the sprayed hut was 43%.

DISCUSSION

Previous observations

Observations on the behaviour of malaria vectors in DDT-sprayed houses have been reported from many parts of the world: Tarzwell & Fisk (1947); Symes & Hadaway (1947); van Thiel & Metselaar (1953); Reid & Wharton (1956); and others. However, it is not clear whether the behaviour of all species of anopheline mosquitos in DDT-sprayed houses is the same; therefore observations dealing with *A. gambiae* and *A. funestus* are of particular interest.

The important investigations of Muirhead-Thomson (1947, 1950) in West and East Africa indicated that the large decrease of anophelines resting in DDT-sprayed houses in day time may give a completely misleading picture of the reduction of mosquitos achieved. In his experiments large numbers of *A. gambiae* and *A. funestus* entered treated houses. But when they tried to rest on the wall after feeding they were irritated by contact with the DDT deposit and left the hut, nearly all of them before picking up a lethal dose. Hocking (1947) on the contrary showed in his investigations in Kenya that despite the irritant effect of the DDT a very high kill could be achieved provided the dose of insecticide applied was strong enough. However, the very discouraging results on the value of DDT in mosquito control given by Muirhead-Thomson have stimulated other investigators in Africa to repeat the experiments. Wilkinson (1951) in Uganda and Davidson (1953) and Burnett (1957) in Kenya have used huts and methods very similar to those described by Muirhead-Thomson. However, their results did not confirm either the complete failure of DDT in controlling *A. gambiae* and *A. funestus* or the promising conclusions of Hocking. The three authors obtained kills between 40% and 80% for the first six months after treatment.

Mortality in present experiments

In the present experiments a considerable drop in the lethal effect of the DDT was observed in subsequent months after spraying. The mortality achieved was never 100% even in the first night after application of the spray. In subsequent months the percentages of mosquitos that were found dead inside the hut, were collected dead from the trap, or died during the following 24 hours decreased markedly (Table 5). Increasing proportions of mosquitos were able to leave the hut. In the first

three months after treatment, 24% of the *A. gambiae* left unharmed, 50% having already fed. During the next three months the proportion leaving unharmed rose to 97%, of which 67% had taken a blood meal before.

These observations are in agreement with our chemical estimations, which showed a very high loss of the DDT deposit over six months. Further indications are the results of bio-assays carried out in the sprayed area, which showed a notable drop in the lethal effect of the DDT residue after four months (Kuhlow, 1960). However, it must be remembered that the results obtained from the chemical and biological assays refer to the wall of the hut only. Many mosquitos were found resting in the thatch of the roof, which represents a considerable proportion of the inner surface of a hut. It is possible (Langbridge, 1958) that on the thatch the DDT residue wears off earlier and therefore the loss of total lethal effect in a hut is shown sooner by the bio-assays. However, it can be observed (Table 3) that the mortality of the mosquitos that died inside the hut in the first month after the various sprayings increased from 26% to 43% and to 58%. Probably this effect was due to the cumulative action of the DDT deposit.

Other observations

Entry. The results obtained in Northern Nigeria show that house-spraying with DDT does not prevent *A. gambiae* and *A. funestus* from entering houses in large numbers. Several workers have observed this before, but they have also noticed a marked reduction in the number of entering mosquitos (Gebert, 1948; Muirhead-Thomson, 1950; Wilkinson, 1951). In our own experiments, a reduction in the number entering was particularly obvious in *A. funestus*: the sprayed hut yielded only 31% of the number that entered the unsprayed hut, while for *A. gambiae* this proportion was 63%.

The reason for the reduction is not yet clear. Wilkinson (1951), from whose wood and fibre huts unrecorded escapes seem unlikely, did not observe increased exit. He concluded that a repellent effect of the DDT must have been present or else a masking of the human smell by the insecticide. Davidson (1953), from the results of his cage tests, discounted any repellent effect but was able to demonstrate a particulate effect probably due to the presence of airborne particles of the insecticide. Reid & Wharton (1956) believe this particulate effect to be the cause of reduction in the number entering. However, this particulate effect is very slight for DDT and does not last long (Davidson, 1953). Our results show a very marked decrease in the number entering even five or six months after spraying, by which time the decrease is unlikely to be due to airborne particles of DDT.

More likely a repellent effect of DDT accounts for the reduced entry, as Downs & Bordas (1951) concluded from their experiments with *A. pseudopunctipennis* in Mexico. Recently de Zulueta et al. (1961) reported a marked repellent effect of DDT in reducing the numbers of *A. gambiae* coming into their sprayed hut in Uganda.

Biting. Most of the mosquitos entering took a blood meal. However, a certain decrease in the biting rate became obvious from the higher percentage of females that left the sprayed hut without feeding. Compared with the unsprayed hut, there was an increase in the proportion of unfed females in the total catch of 13% for *A. gambiae* and 12% for *A. funestus* (Table 4). A similar observation was made by Muirhead-Thomson (1950), who reported an increase of unfed mosquitos of 14% in his treated hut.

Resting. The effect of house-spraying with DDT on the resting of *A. gambiae* and *A. funestus* is clearly shown by the increased number of mosquitos leaving the hut. This rose from 13% in unsprayed hut A to 53% in hut B for *A. gambiae* and from 43% to 67% for *A. funestus*, owing to the irritant effect of the DDT. Unfortunately, this irritant effect is largely independent of the lethal action and is longer lasting. Four to six months after spraying, the proportion of *A. gambiae* leaving the hut was still very high, even higher than in the first three months (Table 3); the same was true for *A. funestus* and *A. pharoensis*. The irritation became particularly obvious when the loss of the lethal effect enabled increasing numbers of mosquitos to leave the hut. Davidson (1953) noticed the irritant effect of the DDT in all the nine months of his investigations in Kenya.

Normal behaviour. Catches on successive days showed that spraying of the hut with pyrethrum in kerosene in the morning did not affect the result of the catch on the following night. Muirhead-Thomson (1947) found that application of kerosene might have a strong repellent effect; but in his experiments the walls were treated with high pyrethrum concentrations, whereas our concentrations were much

lower and the spray fell mainly on the floor-sheets, which were removed from the hut.

Certain differences in house-haunting habits between *A. gambiae* and *A. funestus* were observed in our experiments. A high proportion of the *A. gambiae* entering a hut fed and remained inside; very few specimens left the house during the same night (Tables 2 and 4). As shown in an earlier report (Kuhlow, 1959), there is a noticeable daily movement among the *A. funestus* population of a hut: of the total *A. funestus* entering the unsprayed hut, 12% were gravid and 22% left without feeding; in all, 43% left the hut during the same night. There was also a marked seasonal variation in the proportion which remained in the hut. Similar observations were made by Davidson (1953) in Kenya, who considered *A. funestus* a less house-haunting species than *A. gambiae*.

However, the resting habits of *A. gambiae* and *A. funestus* seem to vary in different parts of Africa. Barber et al. (1932) in Liberia and Hocking & MacInnes (1948) in Kenya conclude from their observations that both species, in all abdominal conditions, show a considerable turnover every night. On the other hand, it has been observed in the Transvaal by de Meillon (1934) and in Tanganyika by Muirhead-Thomson (1951) and Gillies (1954) that almost all *A. gambiae* and *A. funestus* remain inside the huts after feeding, many of them until they are fully gravid.

The less house-haunting habit of *A. funestus* observed in Northern Nigeria may account for the fact that this species still occurs in that area despite six years of spraying with residual insecticides. In other parts of Africa *A. funestus* has vanished very soon after house-spraying, as in the sprayed areas of Mauritius (Dowling, 1953), Swaziland (Mastbaum, 1957) and Tanganyika (Gillies & Smith, 1960).

CONCLUSION

The results obtained showed that a considerable number of local malaria vectors entering DDT-sprayed huts do not rest long enough on the treated surface to acquire a lethal dose and are able to leave the hut unharmed. Under the local conditions the DDT residue showed a rapid loss of its lethal action, but its irritant property remained effective for a long period. Therefore it seems advisable to spray the houses heavily enough to ensure that resting mosquitos acquire a lethal dose before they become irritated. The observations made suggest that a dose of 1.9 g/m² technical DDT twice a year may not be sufficient to interrupt malaria transmission, especially if coverage is not total. Under the special local conditions of Northern Nigeria—with holoendemic malaria, huts built of abosrbent mud, and such efficient malaria vectors as *A. gambiae* and *A. funestus*—the application of a heavier dose of DDT seems indicated.

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RÉSUMÉ

Depuis octobre 1957, toutes les habitations comprises dans la campagne d'éradication du paludisme en Nigeria du Nord ont été traitées par le DDT, depuis que la résistance de *A. gambiae* à la dieldrine et au HCH ont fait abandonner ces derniers insecticides. A la suite du traitement (1,9 g/m² de DDT technique deux fois par an), le nombre des moustiques séjournant à l'intérieur des maisons, ainsi que l'indice parasitaire des habitants, ont fortement baissé, sans que la transmission ait été interrompue pour autant. Il est probable que la proportion des moustiques échappant à l'action de l'insecticide est suffisante pour entretenir la transmission. L'auteur a cherché à préciser le comportement des vecteurs, dans des cases traitées et non traitées, munies de fenêtres-pièges. Dans les habitations non traitées, la plupart des *A. gambiae* reste à l'intérieur après le repas de sang. Chez *A. funestus*, une forte proportion de ceux qui pénètrent le soir dans une habitation la quitte la même nuit.

Dans les habitations traitées, les pulvérisations n'empêchent pas l'entrée des moustiques, mais réduisent cependant leur nombre. Pour *A. gambiae*, le nombre des moustiques qui entrent dans les cases traitées n'est que

63% du nombre de ceux qui pénètrent dans les cases non traitées; pour *A. funestus*, la proportion est de 31%. La plupart des moustiques entrés dans les maisons s'y nourrissent, mais la présence d'une proportion plus forte de femelles à jeun dans les cases traitées indique une certaine baisse du taux des piqûres.

Les observateurs furent frappés du nombre considérable de moustiques qui quittaient les maisons traitées et de la proportion élevée de ceux qui échappaient indemnes. Les chiffres s'élevaient progressivement dans les mois suivant le traitement. Au cours des trois premiers mois, 71% des *A. gambiae* et 73% des *A. funestus* étaient tués. Dans les trois mois suivants, cette proportion n'était plus que 21% et 30% respectivement, ce qui indique une chute rapide de l'action létale du DDT résiduel; les propriétés irritantes, au contraire, subsistaient.

L'auteur conclut que dans les conditions locales rencontrées en Nigeria du Nord, la dose de 1,9 g/m^2 de DDT, deux fois par an, ne suffit pas à interrompre la transmission du paludisme.

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