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MALARIA IN THE PARE AREA OF TANGANYIKA

PART II. EFFECTS OF THREE YEARS' SPRAYING OF HUTS WITH DIELDRIN

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A previous paper (DRAPER and SMITH, 1957) gave a description of this area and of the epidemiology of its malaria, and this paper records the observations on mosquitoes and human malaria during the 3 following years, in which huts were sprayed with the residual insecticide Dieldrin.

The South Pare area is the south-east sector of the Taveta-Pare Malaria Scheme, which in all covers about 3,500 square miles with a total population of 100,000, of whom about one-half lived in malarious places. The total number of huts sprayed in the Scheme was about 15,000, of which one-third lay within the area dealt with here. Observations on the malaria before and after spraying in the north sector of the Scheme have been given elsewhere (SMITH and DRAPER, 1959).

All huts in places where transmission was thought to occur were first sprayed during the latter half of 1955, the spraying of South Pare being completed in November. A water dispersible preparation of Dieldrin was used to give an approximate wall dosage of 80 mg. of Dieldrin per sq. ft. during the first cycle. Subsequent sprayings were done about every 8 months, using half this dosage. The sixth and last spraying in South Pare finished in February, 1959. The insecticide was applied to the inside surfaces of the walls, roofs, and ceilings, but not the eaves, of all inhabited huts and of their separate kitchens and latrines ; beds and other immovable furniture were also sprayed. By the end of the second cycle over 90 per cent. of inhabited huts had probably been sprayed, but each following cycle brought a small increase in numbers, due to new buildings and the discovery of remote hamlets.

The total annual rainfall in inches during the 3 years of spraying was 42 for 1956, 58 for 1957, and 42 for 1958 ; compared with 17 and 52 for 1954 and 1955, respectively. Temperature and humidity records for the years of spraying did not differ appreciably from those for the years of the preliminary observations.

ENTOMOLOGICAL OBSERVATIONS

In the previous paper the area was divided, for purposes of study, into the roadside villages, at the foot of the mountains, where few cattle were kept, and the swamp villages, in the Mkomazi River valley, where there were large herds of cattle, which at night were penned outside houses in open enclosures. In the swamp villages there was much deviation of *Anopheles gambiae* to cattle but, despite this, the malaria transmission was greater than in the roadside villages, because of large numbers of *Anopheles funestus*. The observations

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described before have been continued in both groups of villages, and have been supplemented by several tests to assess the action of the Dieldrin. Four pairs of experimental huts have been maintained, one member of each pair being sprayed.

Densities of the vectors in huts

The effect of the spraying on the numbers of *A. gambiae* and of *A. funestus* caught alive in treated huts is shown in Table 1 and in Figure 1. During the 1st year of spraying the numbers of *A. gambiae* in the roadside villages fell by over 90 per cent., and this decrease was maintained during the 2nd and 3rd years. In the swamp villages, a reduction of over 80 per cent. in the 1st year was increased to over 90 per cent. in the 2nd and 3rd years. Typical *A. funestus* was not taken alive in huts from 7 months after the start of spraying, although an unidentified mosquito of the "*funestus* complex" was occasionally found in huts thereafter. Figure 1 shows that although the numbers of *A. gambiae* in treated huts generally kept at a low level after spraying, they increased in March, 1956, and in the January of the years 1957 and 1959, notably in the swamp villages. These peaks in Figure 1 followed heavy rain in the preceding months, and were probably a manifestation of the delayed killing action of Dieldrin (see later) upon the large numbers of mosquitoes entering huts at these times.

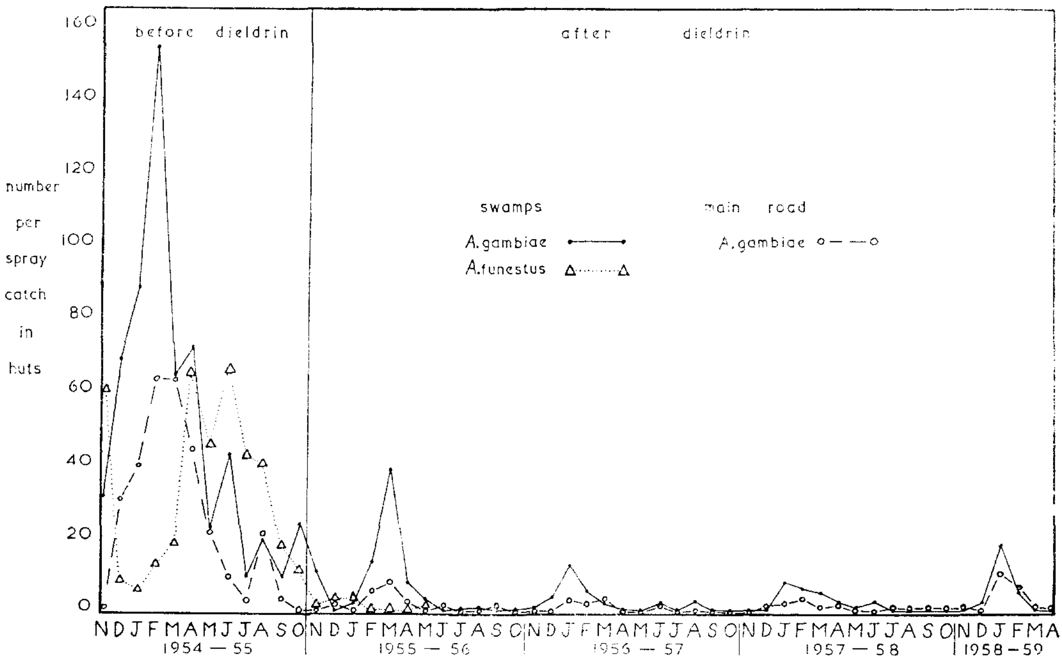

FIG. 1. Numbers of *A. gambiae* and *A. funestus* in spray catches in huts.

Mosquito catches in untreated experimental huts suggested that the actual numbers of *A. gambiae* entering huts in roadside villages were reduced to between one-quarter and one-third of their previous size. The average numbers of mosquitoes obtained from the combined window trap and hand catch in an untreated hut were 6.1 per day during the 1st year of spraying, 8.6 the 2nd year, and 7.1 the 3rd year, compared with a figure of 25.6 for the year before spraying. On the other hand the number of mosquitoes entering huts in swamp villages was not significantly changed. Data are available from spray catches

TABLE I. Spray catches of *A. gambiae* and *A. funestus*. Three-monthly averages of numbers per house per day.

	Before Dieldrin				*After Dieldrin*													
	1955				1955-56				1956-57				1957-58				1958-59	
	Nov. to Jan.	Feb. to Apr.	May to July	Aug. to Oct.	Nov. to Jan.	Feb. to Apr.	May to July	Aug. to Oct.	Nov. to Jan.	Feb. to Apr.	May to July	Aug. to Oct.	Nov. to Jan.	Feb. to Apr.	May to July	Aug. to Oct.	Nov. to Jan.	Feb. to Apr.
Roadside villages *A. gambiae*	24.3	57.7	12.3	8.7	0.6	5.7	0.27	0.16	1.6	2.1	1.5	0.34	1.71	2.75	1.01	0.04	3.91	3.28
A. funestus	3.3	7.7	20.3	6.4	0.01	0.14	0	0	0	0	0	0	0	0	0	0	0	0
Swamp villages *A. gambiae*	63.0	97.7	25.3	18.1	5.2	20.4	1.8	0.9	6.5	3.3	1.8	1.7	3.49	5.39	1.92	0.28	7.31	2.65
A. funestus	25.7	32.3	52.3	24.03	0.47	0.06	0.01	0	0	0	0	0	0	0	0	0	0	0

in 195 untreated native huts detected during the years of spraying. These were mostly new huts built between spraying cycles and, as is customary in Pare, were completed during the rains of November to January, so that they were usually discovered at a time when the production of *A. gambiae* was greatest. The average density of *A. gambiae* in these untreated huts was 32 per catch, while the figure for huts in the same villages at a comparable period before spraying was 39.

The host choice of A. gambiae.

Precipitin tests have been continued on mosquitoes caught inside houses and under eaves, and on those taken in 35 box shelters placed in and around two of the roadside villages, where a few cattle, sheep, and goats are tethered outside the houses at night. In the swamp area, collections were made in vegetation and in crevices in the ground, in a village where the number of animals is high in relation to the human population. The results of tests on mosquitoes from these different sources are summarized in Table II. The results from occupied treated or untreated huts are similar to those before spraying. Catches from a few unoccupied and untreated huts near cattle pens showed that they were resting places for only those *A. gambiae* that had fed on cattle. Eaves of houses, however, harboured more man-fed mosquitoes than before spraying (SMITH, 1958a). This change may possibly be due to the earlier collections having been made in the cool season and the later ones in the hot season, when more people sleep outdoors. The results from mosquitoes resting outdoors showed no detectable change in the host choice of *A. gambiae*.

TABLE II. The host choice of *A. gambiae* after residual spraying.

	Number of smears	Per cent. positive Man	Ox
Roadside villages			
Occupied treated huts	433	86	8
Box shelters	473	20	59
Swamp villages			
Occupied treated huts	3,194	42	50
Occupied untreated huts	549	59	33
Unoccupied untreated huts	78	0	85
Eaves	45	20	62
Natural outdoor shelters	273	0.4	93

Similarly, observations of the numbers of *A. gambiae* feeding on cattle have been continued, using artificial box shelters placed around cattle pens, as previously described. Figure 2 shows the results, before and after spraying, of weekly collections from shelters around different pens. One of these was at Kizerui, in an area where there were few cattle and many huts, and the other was at Bumba, where, conversely, there were many cattle and few huts. In Kizerui the numbers of *A. gambiae* biting cattle were much reduced following the spraying, but in Bumba there was less effect. The differences are thought to be significant, despite the intrusion of variables such as changes in the numbers of cattle, the shifting of pens, the consequent resiting of the shelters, and the availability of natural resting places in vegetation, which compete with the artificial shelters. The effect of this last factor is shown in Figure 2, in which there are three peaks at Bumba corresponding to the dry months when vegetation was sparse. Furthermore, after the vegetation was cut down in June, 1958, the fourth peak was transposed to the wet months. Thus the availability of cattle and of outdoor resting places in the swamp villages causes differences in the observed effects of the spraying on the biting population of *A. gambiae.*

Outdoor biting on man

Collections off human bait between 1900 and 2100 hours in the roadside village of Gonja showed that the average catch of 5.2 per man/night for the year before spraying was reduced to 0.9 for the 1st year, 1.4 for the 2nd year, and 0.5 for the 3rd year of spraying. No typical *A. funestus* was caught biting in these catches from 6 months after the start of spraying.

Dissections of mosquitoes for sporozoites

During the 3½ years after the start of spraying, the following numbers of anopheles from hut catches were dissected : 17,591 *A. gambiae*, 89 *A. rivulorum*, and 16 *A. pharoensis*. Two *A. gambiae* only were found with sporozoite infections, one in 1956 from a fishing settlement with many newly built and unsprayed huts, and the other in 1957 from an isolated hamlet which had never been sprayed. In addition, no infections were found in 5,504 *A. gambiae*, 86 *A. rivulorum*, and 369 *A. pharoensis* caught in box shelters and natural outdoor resting places.

Mortality of A. gambiae *in treated huts*

Totals of 2,951 fed and of 1,377 gravid *A. gambiae* were caught in catching stations during January and February, 1955, showing a ratio of fed to gravid mosquitoes of 2.1 to 1 before spraying. During the same months of the years from 1957 to 1959, 6,852 fed and 964 gravid mosquitoes were caught in treated huts, 2,341 fed and 465 gravid mosquitoes in untreated huts, the ratios of fed to gravid being 7 to 1 for treated, and 5 to 1, for untreated, huts, respectively. These findings suggest that after the spraying there was either an increased mortality in the mosquito population, or a greater proportion of mosquitoes leaving huts half-way through the gonotrophic cycle and not re-entering huts to complete it.

Further information on the mortality of *A. gambiae* in treated huts was obtained from inhabited experimental huts, which had been sprayed with Dieldrin, and were fitted with an exit window trap. The floor of each hut was covered with sheets that were removed each morning, and the numbers of dead mosquitoes counted, a search also being made along the bottoms of the walls. The living and dead mosquitoes in the window trap were also removed and counted each morning, and the trap returned. This procedure was done for 5 successive days, and on the last day was followed by a spray catch, to assess the number of living mosquitoes in the hut (Table III). This shows, firstly, that a substantial mortality occurred within the hut itself, and, secondly, that although some of the mosquitoes were irritated and left the hut, shown by the high proportion in the window trap, many of these had already picked up a lethal dose of Dieldrin. It is probable that, owing to the slow action of Dieldrin (see later), a higher mortality would have occurred had the mosquitoes in the window trap been observed for a longer period. In the course of a more detailed study of the effects of Dieldrin on the behaviour of *A. gambiae* such a delayed mortality was found. It was also found that many mosquitoes were irritated after entering a recently sprayed hut, and left before feeding. Subsequently a proportion of these entered other huts and fed, but did not survive long enough to complete their gonotrophic cycle (Smith, unpublished observations).

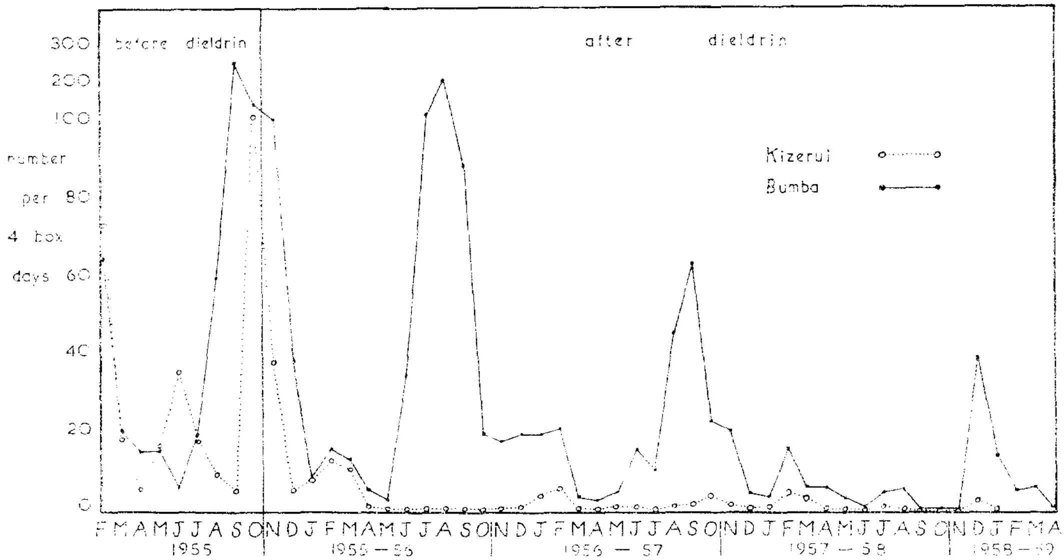

FIG. 2. Numbers of blood fed *A. gambiae* in box shelters around cattle enclosures.

TABLE III. Mortality of *A. gambiae* in treated experimental huts.

	In hut.			*Window trap*		
	Spray catch	No. dead on floor.	Per cent. mortality	Alive	Dead	Per cent. mortality
May to Dec. 1956	10	59	86	15	15	50
Jan. to June 1957	230	256	53	222	312	58
July to Dec. 1957	30	10	25	24	22	48
Jan. to June 1958	200	45	18	287	107	27
July to Dec. 1958	25	18	42	67	26	28
Jan. to Apr. 1959	235	170	42	289	164	36

In contrast to its behaviour in treated huts *A. gambiae* did not leave the untreated experimental huts after feeding to a significantly greater extent. Of 3,297 recently-fed mosquitoes caught in the untreated huts during the 3 years of spraying, 9 per cent. were in the window traps, compared with a figure of 5 per cent. before spraying.

Wall application tests

A test was devised in which small cages of mosquito netting, containing from 20 to 50 *A. gambiae*, were placed against the walls of treated houses. The standard period of exposure was 3 hours, after which the cages were placed in a damp chamber in an untreated hut, and the mortality after 24 hours recorded. Control tests were done on the walls of untreated huts, and from five to eight repetitions were done of each test. The mosquitoes used were of varying ages and stages of ovarian development. The tests were used to study three aspects of the reaction to the insecticide :

(i) The rate of action of Dieldrin. Mosquitoes collected from box shelters were exposed to the wall of a treated experimental hut, and their mortality recorded at 2-hour intervals up to 12 hours afterwards. Four tests, using a total of 186 mosquitoes, showed the following average mortalities : 13 per cent. after 4 hours, 49 per cent. after 8 hours, and 81 per cent. after 12 hours, while an average mortality of 2 per cent. after 12 hours occurred in the controls. This shows that the lethal effect of Dieldrin is slow.

(ii) The period of effectiveness of the residual deposit of Dieldrin. Mosquitoes collected from box shelters were exposed to the walls of huts in several villages at varying intervals after these had been sprayed. The huts included four which had been deliberately left unsprayed after the second cycle. Similar results were obtained in huts with rough unplastered walls as in huts with smooth walls, but very rough walls were not used because of the difficulty of applying the cages to them. In all, 23 tests were done ; and the results from six huts at different periods during the spraying are given in Table IV. They show that high mortalities occurred at all times after spraying, and that even two treatments were sufficient, at least in some huts, to leave a deposit that was active for 18 months.

(iii) Comparison of mosquitoes collected from untreated huts and from artificial shelters around cattle pens. Simultaneous exposure to the walls of treated huts of mosquitoes from these sources produced similar mortalities.

TABLE IV. Mortalities after 24 hours in *A. gambiae* exposed for three hours to Dieldrin treated walls

Locality of treated huts	Details of treated surfaces	Treated huts		Controls	
		Number tested	Per cent. corrected mortality	Number tested	Per cent. mortality
Gonja	5 months after 2nd spray	242	77	309	5
Lower Gonja	7 months after 2nd spray	219	83	240	17
Lower Mpirani	6 months after 3rd spray	137	92	132	7
Gonja	1 month after 4th spray	151	100	150	17
Gonja	15 months after 2nd spray	228	39	236	18
Gonja	18 months after 2nd spray	125	91	131	31

Susceptibility tests

The method used was that of BUSVINE and NASH (1953), mosquitoes being exposed to the insecticide for 1 hour and the mortalities at 24 hours recorded. Regression lines were calculated from the results of tests on 380 recently-fed *A. gambiae* from untreated huts, and on 609 from shelters near cattle pens, done during June, 1957. These showed the median lethal concentrations of Dieldrin to be 0.08 and 0.1 per cent., respectively, providing further evidence that mosquitoes from both sources were equally susceptible. Using a test kit provided by WHO, and mosquitoes from box shelters, a M.L.C. of 0.12 per cent. for Dieldrin and of 0.9 per cent. for DDT were obtained.

Over 3,000 wild-caught *A. gambiae* were screened against papers treated with 0.4 and 0.5 per cent. Dieldrin, and there were no resistant survivors. (SMITH, 1959a).

MALARIA IN THE HUMAN POPULATION

During the 3 years of the spraying, surveys have been repeated in the roadside and swamp villages in months corresponding to those of the surveys done before spraying, as given in Part I of this study. The findings at the later surveys are given in Table V and Figure 3, and show a steady fall in the spleen and parasite rates, starting within 6 months of the beginning of the spraying. Reductions in the roadside villages have been slightly

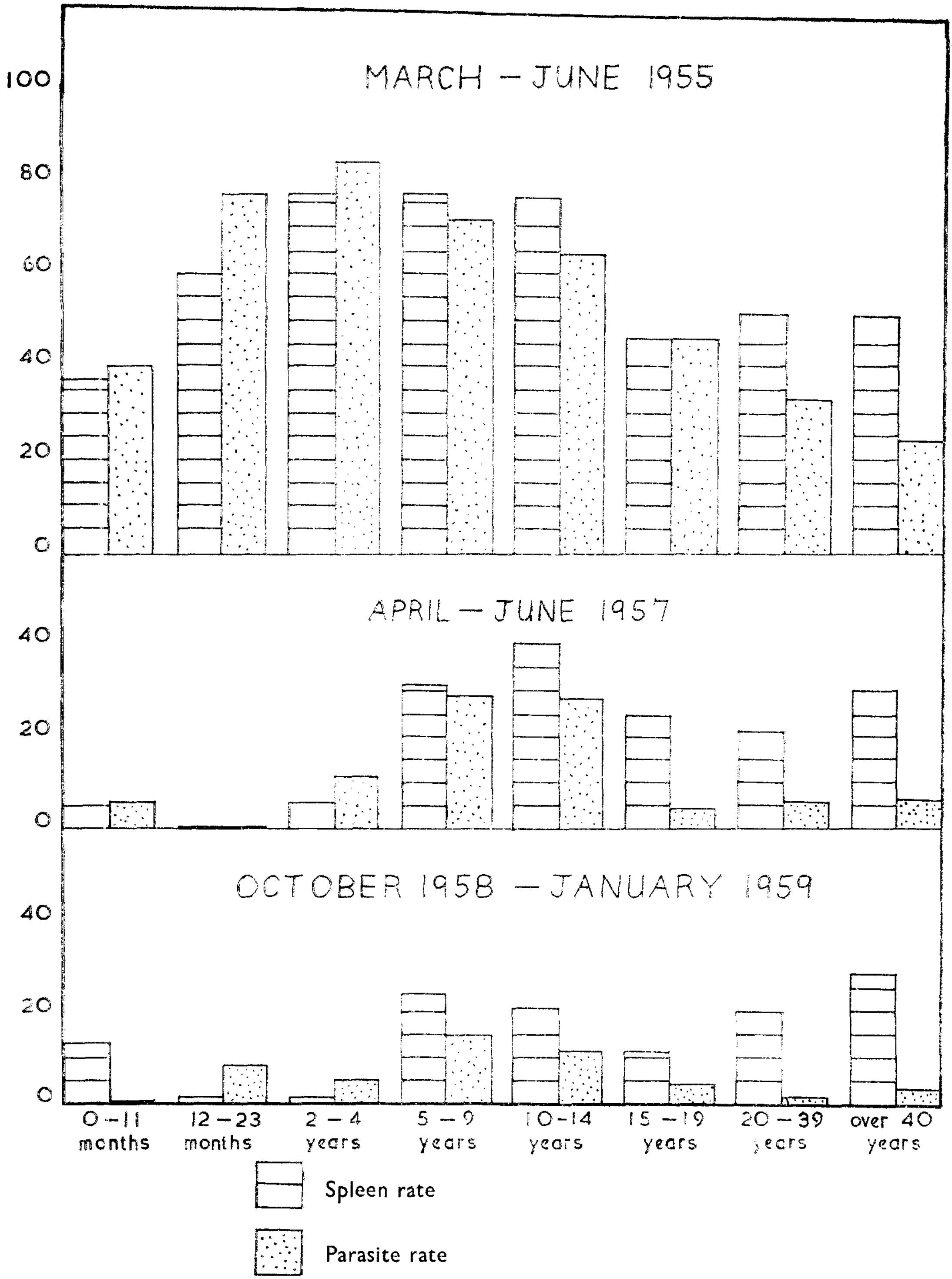

FIG. 3. Spleen and parasite rates, South Pare swamp villages.

greater than in the swamp villages, and in the latter there is still a moderate parasite rate in the older children. This is discussed later. Spleen rates of children have fallen proportionally more than those of adults, the latter, notably in the swamp villages, remaining at a third to a half of their previous levels. This may be, on the one hand, because some irreversible fibrosis of the spleen had occurred in many of the adults while, on the other hand, the children have continued to grow, a circumstance that can make a spleen less easily palpable. Table VI shows the relative incidence of the different species of malaria parasite in positive films, at surveys before and after the spraying. As might be expected, *Plasmodium malariae* became relatively more common in 1956 and 1957, but since then has become scarcer. *P. vivax* and *P. ovale* remained rare. Table VII shows the mean densities of infections of of *P. falciparum* in positive films, for years before and after spraying. The general trend of densities is downwards, suggesting the waning of established infections. Excluding the infants, discussed later, some of the figures, such as those for the age-groups 10 to 14 years and 15 to 19 years in 1958-1959, suggest, however, that a few new infections may have been superimposed.

TABLE V. Spleen and Parasite rates :

Roadside villages.

Age-group		1956 Mar.-May	1957 Mar.-May	1958 Mar.-May	1958-59 Aug.-Jan.
0-11 mths.	No. examined	47	66	56	67
	Spleen rate	4	2	4	0
	Parasite rate	4	2	4	0
12-23 mths.	No. examined	44	48	54	66
	Spleen rate	9	0	2	2
	Parasite rate	21	8	4	2
2-4 yrs.	No. examined	107	158	110	177
	Spleen rate	22	7	2	2
	Parasite rate	33	12	6	3
5-9 yrs.	No. examined	253	311	302	328
	Spleen rate	41	22	13	11
	Parasite rate	39	16	11	5
10-14 yrs.	No. examined	267	239	272	270
	Spleen rate	47	25	21	15
	Parasite rate	35	25	10	6
15-19 yrs.	No. examined	107	86	48	60
	Spleen rate	17	9	17	0
	Parasite rate	23	7	2	2
20-39 yrs.	No. examined	208	231	148	362
	Spleen rate	24	13	9	10
	Parasite rate	16	4	6	22
Over 40 yrs.	No. examined	116	99	82	119
	Spleen rate	43	19	27	7
	Parasite rate	11	4	4	3

TABLE V.—*Continued*

Swamp villages.

Age-group		1956 April-December		1957 Apr.-June	1957 Oct.-Dec.	1958 Mar.-June	1958-59 Oct.-Jan.
0-11 mths.	No. examined	19	22	43	35	55	61
	Spleen rate	5	14	5	3	4	13
	Parasite rate	17	0	6	3	2	0
12-23 mths.	No. examined	21	18	25	31	52	53
	Spleen rate	29	0	0	0	8	2
	Parasite rate	57	13	0	0	4	8
2-4 yrs.	No. examined	48	42	81	80	112	118
	Spleen rate	44	33	6	6	8	2
	Parasite rate	45	40	12	16	10	5
5-9 yrs.	No. examined	108	63	168	74	213	225
	Spleen rate	64	58	32	35	31	24
	Parasite rate	61	41	29	20	16	15
10-14 yrs.	No. examined	87	50	134	67	132	148
	Spleen rate	74	41	40	37	34	21
	Parasite rate	53	29	28	12	20	12
15-19 yrs.	No. examined	57	52	87	98	100	92
	Spleen rate	44	36	25	22	19	12
	Parasite rate	29	15	4	7	9	4
20-39 yrs.	No. examined	233	152	288	299	293	293
	Spleen rate	39	29	22	22	23	20
	Parasite rate	18	12	6	2	3	2
Over 40 yrs.	No. examined	133	136	251	266	288	255
	Spleen rate	48	34	30	26	35	28
	Parasite rate	19	9	7	8	4	3

TABLE VI. Relative species-incidence of malaria parasites.

	1954 Feb.-June	1954 July-Dec.	1955 Mar.-June	1955 Aug.-Dec.	1956 Mar.-May	1957 Jan.-June.	1957 July-Dec.	1958 Jan.-June	1958-59 Sept.-Jan.
Total infections	481	837	1294	562	659	208	95	191	147
P. falciparum Per cent.	91	81	86	86	74	86	85	90	93
P. malariae Per cent.	8	14	12	9	23	11	13	9	6
P. vivax and *P. ovale* Per cent.	1	5	2	5	3	3	2	1	1

TABLE VII. Mean density of infections with *P. falciparum* per c.mm. (geometric mean).

Age-group		1954	1955	1956	1957	1958-59
0-11 months	Density	3162	923	463	240	891
	No. Infections	27	303	48	17	18
12-23 months	Density	1832	1349	759	389	1047
	No. infections	59	180	36	11	25
2-4 years	Density	902	3273	339	341	447
	No. infections	180	166	51	30	26
5-9 years	Density	292	676	355	237	266
	No. infections	260	304	108	80	87
10-14 years	Density	189	221	184	137	355
	No. infections	177	295	103	74	68
15-19 years.	Density	130	211	178	100	343
	No. infections	52	103	32	14	15
20-39 years	Density	121	102	121	100	94
	No. infections	65	123	30	16	19
Over 40 years	Density	96	65	64	38	65
	No. infections	27	51	13	12	16

In addition to those brought to the general surveys, infants were regularly examined at special infant clinics run by the Scheme, the aim having been to obtain a blood film from each infant about every 3 months, and at any other time at which it was suffering from a febrile illness. During the last 2 years visits were made every 6 months to more distant villages and hamlets, in order to examine infants born since the start of spraying who would not otherwise have had blood films taken from them. Table VIII and Figure 4 show the results of the examination of these blood films, by approximate quarterly periods, for years before and after the spraying. The parasite rates for the infants under a year old continue to fall from the end of 1955 until the latter part of 1956, when all would have been born since the start of spraying ; while rates for infants between 1 and 2 years continue to fall until early 1957. Since then the rates have remained at a low level. Table IX shows the actual numbers of infants examined, born since the start of spraying, and an analysis of the new infections found amongst them. Most of these infants who, by 1958, approached three-quarters of the infant population of the South Pare plains, would have been examined several times in a year. This Table shows that almost one-half of the infections may have been acquired outside the sprayed zone. It is significant that, of the 41 local infections, 34 (83 per cent.) were found in infants from the swamp villages. Additional evidence of continuing transmission was provided by the finding of new infections in children aged 2 and 3 years, who were known to have been parasite free at previous surveys, and who were said not to have travelled.

TABLE VIII. Infant parasite rates, by quarterly periods.

	1954 April to June	1954 July to Dec.	1955 March to June	1955 July to Oct.	1955 Nov. to Dec.	1956 Jan. to Mar.	1956 April to June	1956 July to Sept.	1956 Oct. to Dec.
Age-group Months									
0-11	30	23	39	33	36	13	6	3	1
No. examined	66	74	203	323	203	356	323	354	357
12-23	62	55	57	58	49	23	25	11	5
No. examined	63	64	150	116	67	91	83	65	63

	1957 Jan. to Mar.	1957 April to June	1957 July to Sept.	1957 Oct. to Dec.	1958 Jan. to Mar.	1958 April to June	1958 July to Sept.	1958 Oct. to Dec.	1959 Jan. to Mar.
0-11	1	2	2	3	1	3	2	1	2
No. examined	623	308	206	225	214	493	191	273	190
12-23	4	1	4	6	10	7	2	5	2
No. examined	114	78	46	84	60	162	47	130	86

TABLE IX. Histories of infections in infants up to 2 years old, born since the start of spraying.

	1957 Jan.-Dec.	1958 Jan.-Dec.	1959 Jan.-Mar.
No. of infants examined	620	850	276
No. infected, with no safari history	12	26	3
Per cent.	1.9	3.1	0.8
No. infected with a history of safari	9	17	2
Per cent.	1.5	2.0	0.7
No. infected untraced or history unreliable	7	2	1
Per cent.	1.1	0.2	0.4
Total	28	45	6
Per cent.	4.5	5.3	1.9

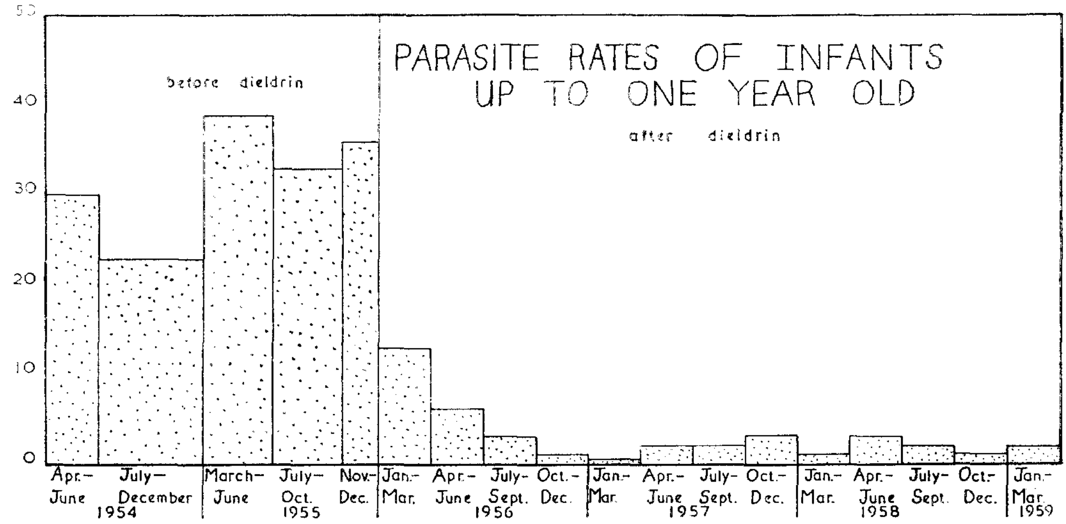

Fig. 4

Discussion

All the entomological observations show that the dosages of Dieldrin used caused considerable mortality among the vectors of malaria which entered sprayed huts. This confirms the work of Davidson (1953) and of Burnett (1957) at Taveta, in the northern sector of the Scheme. This mortality is shown by the great reduction in the numbers of mosquitoes caught alive in treated native huts (Table I and Figure 1) when these and the findings in the treated experimental huts (Table III) are viewed together. The slow action of Dieldrin has been demonstrated. By 7 months after the start of spraying, *A. funestus* type, which was known to feed almost wholly on man, had apparently disappeared. Catches in untreated huts show that the densities of *A. gambiae* were reduced in the roadside villages ; but that in certain swamp villages they were undiminished. This difference was probably due to their feeding on cattle in the swamp villages and the availability of natural outside resting places. A situation in contrast to that described here was found in the village of Mata in the Taveta area (Smith, 1958a ; Smith and Draper, 1959). There, although large numbers of *A. gambiae* fed outside houses on cattle, a paucity of natural resting places caused most of them to enter huts to rest, so that spraying reduced their numbers.

The susceptibility and screening tests show that resistance in *A. gambiae*, of the type reported to occur in West Africa (Armstrong et al., 1958 ; Davidson, 1958) was not found in Pare. The equal susceptibility of *A. gambiae*, whether caught in huts or around cattle pens, conforms with the previously expressed hypothesis that these are not separate strains. This is also supported by the observation that there has been no change in the host choice of hut resting mosquitoes. Resistance to Dieldrin, however, occurred in *Cimex hemipterus*, *Culex p. fatigans*, *Pulex irritans*, and *Pediculus h. corporis* (Smith 1958b, 1959b, in press).

The most important epidemiological result of the increased mortality of *A. gambiae* was the reduction in its infectivity. This, with the disappearance of *A. funestus*, was responsible, in the phraseology of Macdonald (1957), for lowering the basic reproduction rate of malaria below unity, so that there was a progressive decline in the human malaria indices. It seems certain, however, that some transmission still continued up to the end of the observations, particularly in the swamp villages, proved by the finding of new and locally acquired infections in infants and young children. The figures of parasite densities and, possibly, those of the relative incidence of the different parasite species, also suggest that some mosquitoes were able to bite man and avoid contact with the Dieldrin long enough to transmit *P. falciparum*. There was no lack of a human reservoir of infection ; at the last surveys overt gametocyte carriers numbered up to 4 per cent. of the older children. In evaluating possible causes of this residual transmission, it is of importance that the only infected mosquitoes found were from villages where there were many unsprayed huts. The presence of such huts was due to several reasons. Firstly, there was the missing by the spraying teams of remote hamlets. One such hamlet, in which one of the infected mosquitoes was found, was revealed by the arrival at a local hospital of a number of infected children from it. Secondly, there was the building and reconstruction of huts between spraying cycles. As has been pointed out earlier, these were usually completed and first occupied at a time when the breeding of mosquitoes was at its peak. With an 8-month cycle this period fell between sprayings on several occasions. At one village, lower Mpirani, in the swamps, which was visited between the fourth and fifth cycles, almost 20 per cent. of 232 huts were found to be newly built and unsprayed. Records showed that for the whole area the annual turnover of huts was in the region of 10 per cent., but in some places, such as the above, there were local concentrations of new huts owing to their having been built in groups within easy reach of a water supply. Another important factor in assisting transmission was the common habit of sleeping outdoors during the hot weather, often under the projecting eaves of huts, which, being unsprayed, provided safe resting places for mosquitoes which fed on the sleepers. This also has been referred to before. Huts numbering 126 in different swamp villages were visited during the evenings in February, 1959, and 86 people, from 37 huts, were found sleeping outdoors. From this it is estimated that about one-fifth of the population was sleeping out. The protection of crops at night from the ravages of wild pigs was another occasional cause of exposure. Finally, of importance in the swamp villages, the frequent deviation to cattle and resting in vegetation of *A. gambiae* would, in addition to keeping up its numbers, assist the survival to an infective stage of mosquitoes fed on gametocyte carriers. We consider that a combination of these factors was sufficient to enable *A. gambiae* to maintain a small amount of transmission, even though none was found infected in sprayed villages.

The persistence of comparatively high parasite rates, mostly due to *P. falciparum*, in the older children deserves comment. There are three possible explanations :

1) That some new infections were being acquired outside the sprayed zone, as it was necessary to travel only some 40 miles to the south to enter country where malaria remains uncontrolled. In questionnaires in 1957 and 1958, some 10 to 15 per cent. of children and 20 to 30 per cent. of adults admitted to having passed one or more nights outside the sprayed zone during the preceding year. The occurrence of infections in infants who had travelled outside has been described. Although it is considered unlikely that more than a small proportion of these people would have become infected on their travels, this is an important problem in assessing control in a scheme of this size, where it is contiguous to malarious

country. It implies that there would always be a small but regular flow of infected people returning to the area, of whom some, particularly the infants, would be gametocyte carriers.

2) That the persistence of the erythrocytic stage of *P. falciparum* under natural conditions is longer than has been found in experiments, such as those of JEFFERY and EYLES (1954). This possibility was suggested by the finding of parasites 2 and 3 years after the spraying started, in children who were known to be previously infected, who claimed never to have left the sprayed zone, and who lived in places, such as Kisiwani, where there had been dramatic and sustained reductions in the vectors.

3) That there was more transmission occurring than was shown by the few autochthonous infections found in infants, because a number of infant infections were being suppressed before they became patent, as is known to occur sometimes. Against this can be set the reduction in the numbers of infective mosquitoes. It is possible that infant parasite rates may not always be reliable criteria of the efficacy of control at the lower levels of transmission.

To sum up, our observations during 3 years of residual spraying with Dieldrin show that this was sufficient to cause a progressive decline in the incidence of malaria, but, for various reasons, some transmission probably continued throughout. Continuation of the spraying might bring a further reduction in malaria, but it is doubtful whether, under local conditions, this could ever proceed to complete extinction of transmission. Some modification of the method of spraying, such as a shortening of the cycle or the inclusion of the eaves of huts, might contribute to greater success.

SUMMARY

1) A sequel to an earlier paper describes the effects, during 3 years, on the vector mosquitoes and on the human malaria of the spraying of huts with the residual insecticide Dieldrin.

2) Typical *A. funestus* completely disappeared and there were great reductions in the numbers of *A. gambiae* found alive in huts. The population of *A. gambiae* was also reduced, except in places where there were opportunities for extensive feeding on cattle. There were no changes in the host choices of *A. gambiae.* In many dissections for sporozoites the only infected mosquitoes found were from inadequately sprayed places.

3) The action of Dieldrin was studied. Although it caused some irritation and its lethal action was slow, Dieldrin, in the dosages used, was found to cause a high mortality amongst *A. gambiae* coming into contact with sprayed surfaces, and this effect was very persistent. No change in susceptibility to Dieldrin occurred in *A. gambiae*, but this was found in other arthropods.

4) There was a considerable fall in all human malaria indices, but evidence from several sources suggested that a low degree of malaria transmission continued throughout.

5) Possible reasons for this are discussed, with the causes of persistent parasites in older children.

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