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DIFFICULTIES IN MALARIA ERADICATION CAMPAIGNS DUE  
TO THE BEHAVIOUR OF THE VECTORS<sup>1</sup>

J. Mouchet and J. Hamon  
Overseas Scientific and Technical Research Office, Paris,  
Centre Muraz and Bobo-Dioulasso

1. Introduction

Although there has been great progress in the eradication of malaria in the world in the past few years, several campaigns in Africa are marking time. In some regions especially, transmission of malaria persists despite total coverage with insecticides and although the anopheline vectors are normally susceptible to the preparations employed.

This persistence in transmission is due to a number of related phenomena, among which entomological factors are of considerable importance. But the behaviour of the vector is itself closely linked to that of man, who provides its food and often its habitation while its survival is very largely determined by environment. These factors are so closely interrelated that it is difficult to determine precisely their respective importance or to study them separately.

It is not, therefore, surprising that authors studying the persistence of transmission in treated regions have rarely been able to give a simple explanation of these complex phenomena which bring so many factors into play. Moreover, most field teams are not sufficiently equipped to study such problems, which are sometimes more properly within the field of research.

The various factors that help to maintain the transmission of malaria will be separately considered hereunder before discussion of their significance in various antimalaria programmes in the African region.

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## 2. Reasons for the persistence of malaria transmission in treated regions

Malaria can be transmitted inside or outside habitations or simultaneously in both places.

### 2.1 Transmission within habitations

This is transmission by anopheles that bite inside habitations. These anopheles are susceptible to insecticides sprayed on the walls to the extent that they settle on such walls before biting man, or rest on them to digest their blood-meal. Certain species or individuals do not remain long enough on treated surfaces to absorb a lethal dose of insecticide and emerge unscathed to continue their gonotrophic cycle outside the habitations. This rapid exodus from treated houses may be due to a natural exophilic tendency or to the direct or indirect action of the insecticide deposits.

#### Natural tendency to exophily

Even in untreated regions, not all anopheles show the same tendency to remain in habitations while they digest their blood-meal. Certain species such as A. moucheti, and in continental Africa A. gambiae and A. funestus, often accomplish almost the whole of their gonotrophic cycle inside dwellings. On the other hand, such species as A. nili and A. pharoensis do not remain inside for long after their blood-meal. Even within a single species the degree of endophily (Hamon & Mouchet, 1961) can vary according to environmental conditions from region to region or, within a region, from one season to another (Hamon et al., 1959).

#### Irritant effect of insecticide treatment

Since it was first noted by Metcalf et al., 1945, a great many authors have reported the irritant effect of DDT and this effect is, to some extent, a characteristic of many insecticides. When mosquitos alight on a wall sprayed with DDT their degree of irritability forces them sooner or later to seek a more satisfactory resting-place. Under natural conditions, these irritated anopheles tend to leave habitations treated with DDT rapidly before or after a blood-meal. Most entomologists who have studied the behaviour of anopheles in treated houses with outlet traps have noted this phenomenon.

In 1960, Muirhead-Thomson drew attention to the behaviour of vectors exposed to insecticide. He introduced the general term "behaviouristic avoidance" to describe the tendency of mosquitos to avoid treated surfaces. This term embraces the "natural behaviouristic avoidance" already existing in many anopheline populations and "behaviouristic resistance" acquired as the result of the selective pressure of insecticides. The most representative case of this latter phenomenon is provided by the A. albimanus population of Rio Chagres (Panama) which became hyperirritable as a result of 20 sprayings with DDT (Trapido, 1952 and 1954) - with the proviso that the conclusions drawn from field observations need to be irrefutably confirmed by laboratory observation. However, whether natural or acquired, this "behaviouristic avoidance" is a major factor in the exodus of anopheles from treated houses. The rapidity with which mosquitos can abandon treated habitations clearly depends upon the type of construction and on the number of outlets either incorporated in the construction or due to disrepair of walls.

#### Survival of anopheles in treated houses

The duration of the stay in treated habitations and the toxicity of the walls are the two elements which together determine the death or survival of anopheles in treated houses.<sup>1</sup> The toxicity of the insecticide-coating usually declines fairly regularly in the months following application owing to chemical or physical removal of the insecticide, mechanical alteration of the walls, introduction of new, untreated surfaces, etc. On the other hand, there is little variation in the duration of the "anopheles-insecticide" contact, at least in the case of DDT, since the irritant action of the poison does not seem to be dependent on its concentration or on the residual dose on the surface (Duport et al., 1959; Mouchot et al., 1961).<sup>2</sup>

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<sup>1</sup> Mosquitos may survive not only because they leave the habitations safe and sound, but also because outside they find places without insecticide where they can take a meal.

<sup>2</sup> This does not seem to be valid for all species. A. sundaicus, for example, appears to be more irritated by 4% DDT concentrations than by 2% papers (Muir, personal communication).

Therefore, the mortality of anopheles entering the habitations decreases as the period since treatment increases. Kuhlou (1961) has reported that in north-west Nigeria the mortality of A. gambiae and A. funestus entering experimental huts treated with 2 g/m<sup>2</sup> of DDT was more than 70% in the first three months after treatment, and less than 30% in the next three months. Even shortly after treatment, survival chances can be very high for species that do not remain long on treated walls.

#### Conditions under which transmission persists

The fact that an anopheline vector avoids surfaces treated with insecticides within houses does not automatically imply that it will become infective (Van Thiel, 1951; Gabaldon, 1953).

If the irritant action of the insecticide is always operative before the mosquito has bitten man, the mosquito can neither become infected, nor, if it is infective, transmit the infection. If the phenomenon is only partial, the sole result will be a reduction in the man-anopheles contact and this may assist malaria eradication campaigns. This has been observed for A. sacharovi in Greece by Zulueta (1959) and for A. culicifacies in Gujarat, India, by Luen & Salaby (cited by Hamon & Garret-Jones, 1962). If, on the other hand, freshly engorged mosquitoes become irritated it tends to favour continuance of transmission. Both types of action are found together in the region of Bobo-Dioulasso, Upper Volta, and probably in many other African regions, where they cause persistence of malaria transmission at a very reduced level by A. gambiae, A. funestus and A. nili (Hamon et al., 1959a).

Only females that escape after a blood-meal can become epidemiologically dangerous and then only if they survive for long enough to accomplish the extrinsic Plasmodium cycle. For a species that is normally endophilic, the external environment may be unfavourable either to the survival of the species or to the development of the extrinsic Plasmodium cycle. There will, therefore, be great variations in the responses of anopheles to the insecticide treatment in different parts of the distribution area of a given species, and from season to season in a given zone (Hamon, 1962). One of the most typical examples is the response of

A. funestus to insecticides: it disappears in East African and in the forest zones of West Africa, whereas it remains in the savannah areas of West Africa and sometimes continues its role as vector (Livadas et al., 1958; Gillies and Smith, 1960; Cavalie & Mouchet, 1961; Escudie et al., 1962). The escape of some females from habitations after a blood-meal will thus be more or less significant from the epidemiological point of view according to the conditions they find in the external environment.

The persistence of malaria transmission in treated regions is directly related to vector density and may only occur in their breeding season since malaria transmission declines when density is below a certain level (MacDonald 1957). The maintenance of the species despite the use of insecticides may be assisted between breeding periods by the presence of cattle or big game which enable the females to feed and reproduce without entering treated houses. Furthermore, certain mosquitos that have become infected on man may then draw nourishment from other hosts on several occasions, become infective and transmit malaria even though they have had minimum contact with treated walls. In certain conditions therefore, zoophilic tendencies may be a factor in the persistence of malaria transmission in treated regions.

#### Degree of malaria endemicity

None of the phenomena previously mentioned will have the same meaning in a hypo-endemic region and in a holo-endemic area. A fairly slight additional mortality of vectors in treated habitations may possibly be sufficient to halt transmission of malaria where incidence is low, but may be without effect in zones of high endemicity. The mortality rate needed to halt transmission in a given region remains so far theoretical, since experimental verification has not yet proved possible.

#### 2.2 Transmission outside dwellings

All anthropophilic anopheles will bite outside dwellings when their host is outside and in no human group do all the members shut themselves inside their houses after dusk. It therefore follows that inasfar as vectors have not been eradicated, cases of transmission outside houses remain possible in all malaria eradication campaigns.

However, this factor should not be blamed for the setback to many projects. Only when there is a certain combination of circumstances can transmission be considered as a problem to be dealt with in an eradication campaign and not as a mere accident without epidemiological importance.

#### Human factors

A large proportion of the population must sleep out of doors during that part of the night when the vectors are active. This presupposes warm, dry nights, which can only apply to part of the year and then mainly in the savannah.

#### Entomological factors

The vectors must be sufficiently plentiful during the period when the people sleep out of doors. In Africa there are usually few vectors in the hot, dry season. Finally, after having bitten, the females must find conditions out of doors in which they can survive for long enough to become infective. These conditions are not satisfied as frequently as might seem to be the case at first sight. When transmission outside houses is given as the cause for a setback in an eradication campaign, the situation needs to be examined with care.

### 3. Technical problems due to the behaviour of vectors in the African region

In tropical Africa, where malaria eradication has made relatively little progress, the many campaigns and pilot projects have been checked by the behaviour of the two main vectors, A. gambiae and A. funestus. It is a matter for regret that very little information has been given on the campaigns in Senegal, Togo, Dahomey, Liberia, Ghana, and Northern Nigeria so that the study of the causes of success or setback is difficult.

#### 3.1 West Africa

In West Africa the widespread use of DDT has been dictated by the resistance of A. gambiae to dieldrin. The principal cause for setback in the three campaigns in the savannah zone for which information is available (Northern Cameroun (Cavalié & Mouchet, 1962), Northern Nigeria (Kuhlow, 1961) and Upper Volta) would appear to be

the behaviouristic avoidance of A. gambiae and A. funestus and it seems that an additional factor in the first two campaigns was the rapidity with which deposits of DDT wettable powder became ineffective on straw surfaces.

The results seem better in the forest zone (Livadas et al., 1958) possibly because environmental conditions are less favourable to A. gambiae and A. funestus. In the pilot zone of Yaoundé (Southern Cameroon), transmission seemed to have been interrupted in 1958 (Livadas et al., 1958) but in 1960, after A. gambiae had become resistant to dieldrin and DDT treatment had been inadequate, there was a marked increase in malaria (Choumara, personal communication). At the present time it is difficult to say whether it will be possible to obtain interruption of transmission with DDT only.

### 3.2 East Africa

The exophilic mode of life at high altitudes and latitudes does not favour the transmission of malaria in East Africa, and pilot projects and eradication campaigns seem to have been more successful than in West Africa. Moreover, since A. gambiae has not developed resistance to insecticides of the dieldrin-BHC group, there has been no need to use DDT.

In Tanganyika (Pare-Taveta), eight-monthly treatment with dieldrin has effected a considerable reduction in the intensity of transmission, without halting it entirely. The species responsible for transmission is undoubtedly A. gambiae, but the exact causes of the setback are not known (Smith & Draper, 1959; Draper & Smith, 1960). It would, however, appear that the most likely causes are exophily, exophagy, and zoophily. It is likewise possible that a pessimistic conclusion has been drawn prematurely after too short a period of spraying since the time needed for eradication may be up to five years (Gabaldon, 1956).

In Southern Rhodesia, Swaziland and the Union of South Africa, the obstacles to interruption of transmission appear to be less serious than in West Africa.

#### 4. Conclusions

The technical problems referred to above concern a vast zone extending at least from Senegal to the Sudan and from the Congo to the southern limit of the Sahara, with the possible exception of some forest zones and high altitude areas. They may also apply to other regions since pilot projects are not very numerous in Africa and the results of many of them are not known.

These technical problems should be solved before large-scale eradication campaigns are established. In regions where dieldrin cannot be used owing to the resistance of A. gambiae, six-monthly application of DDT ( $2 \text{ g/m}^2$ ) does not give very satisfactory results and it is difficult to shorten the interval between spraying owing to the difficulty of movement in the rainy season, and also owing to the high cost of this treatment.

New research is needed to establish the optimum conditions for the use of existing insecticides, and especially to produce new, active and non-irritant insecticides.

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