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WHAT RESULTS CAN WE EXPECT FROM THE USE OF AERIAL METHODS IN MALARIA CONTROL?

by

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The spectacular success obtained at Leopoldville in the control of Simulium damnosum by means of aircraft-spraying insecticides led the Government of the Belgian Congo to institute a "sanitary flight" consisting of a C.47 aircraft and three Sikorsky S.51 helicopters. In 1955 the latter were replaced by three Sikorsky S.55 machines, intended for insect control throughout the Belgian Congo. With the C.47 it is possible to discharge 2750 litres of insecticide on each flight. Each of the second type of aircraft carries 400 litres of insecticide alongside. Two different types of discharge were employed. Fogging was used mainly by the helicopters, whereas spraying was carried out in particular by the D.C.3. The fogging method consists in injecting the insecticide mixture into the engine exhaust pipe. The spraying method is sufficiently well known for it to be unnecessary to dwell on it here. Various products were employed. We finally adopted the Gesarol NL formula, containing 17% p.p' DDT, weight/volume, with the addition of an adhesive product increasing the residual properties of the insecticide. The main advantage of this formula is its non-inflammability, an important factor when the product is injected into the engine exhaust pipe (fogging). The second advantage of Gesarol NL is its residual period of about four days when it is used as a thermal aerosol during the rainy season. Numerous trials were carried out to determine the dose which reached the ground and its effectiveness against insects. In every case these trials were carried out under conditions as comparable as possible. The conditions laid down for the helicopter were as follows:

height	30 metres
speed	220 kilometres per hour
rate of discharge . .	50 litres/minute

These figures were adopted during the trials because they represent the mean of the normal working conditions for the aircraft and the results given by the trials were therefore as near as possible to those actually obtained during the disinsecting operations. Wind conditions were of course the only ones which were beyond our control and the experiments were carried out under comparable conditions: nose of the aircraft headed into a very slight wind, never more than 45^{o} from the axis of flight. Statistical analysis of the data collected indicates the following figures as suitable for use in practice. The helicopter treats a strip 120 metres wide by "fogging" in a rather irregular fashion. The concentrations found on the ground range from 50 mg per square metre, under the axis of flight, to 10 mg per square metre. By reason of the gyratory movement of the insecticide fog, certain points receive much weaker doses. The curve indicating the general trend of distribution (without taking accidental variations into account) indicates an average dose on the ground of between 11 and 12 mg of p-p' DDT per square metre. In other words, the dose of 20 mg per square metre found by Dr Wanson to be effective for imagocidal purposes in the campaign against Simulium damnosum, which dose we had decided to adopt for mosquito control, can only be obtained by flights along axes about 60 metres apart. As a result of overlapping, such treatments at intervals of 60 metres finally give the required dose almost everywhere. Since the aero-dynamic characteristics of the D.C.3 are different from those of the helicopter, the insecticide distribution curve takes a different form. The doses vary, on the average, from 10 mg at 150 metres from the axis of flight to 130 mg at 0 metres. This indicates that repeated passages 100 metres apart would ensure, through overlapping, a dose of p-p' DDT of at least 100 mg per square metre of surface treated. This figure makes it possible to apply in five passages a so-called "agricultural dose" of 500 g per hectare, whose residual properties persist for nearly three weeks.

We also endeavoured to determine the amount of insecticide present per unit volume of air. The results of these tests were very variable, but may serve as a rough guide: the concentration of p-p' DDT per cubic metre of air did not exceed a maximum of one gram and did not fall below 78 mg per cubic metre after three minutes. When it is remembered that the requisite concentration when aerosol bombs are used in closed premises is 5.3 mg per cubic metre of air during three minutes, it can be seen that a very satisfactory result is also obtained in this respect. Consequently, the results as a whole indicate that a theoretical treatment with 396 g of DDT per hectare actually leaves on the ground, taking into account irregularities of distribution, a concentration of 110 g per hectare, i.e. a dose four times smaller. In the case of the D.C.3 the dose produced on the ground represents about one-third of that discharged. It was found, during repeated treatments, that this dose has a residual action lasting about four days. Furthermore, the concentration per unit volume of air treated by fogging is sufficient dosage to kill any adult mosquitos present. This fact is clearly very important. As regards the size and the density of the droplets, we were able to determine that, just under the axis of flight, the droplets had a diameter of 200 to 600 microns, probably due to inadequate aerosolisation. Over the remainder of the strip treated, 89% of the droplets were found to be between 10 and 100 microns in diameter, a size particularly favourable for insecticidal action. An average of 82 droplets per square centimetre was found on glass sheets. Consequently the insecticidal coverage is of very high quality. We also carried out biological control tests in support of our chemical tests so as to determine the lethal dose for insects. For this purpose we employed flies which were very sensitive to the insecticide in order to determine what width of the strips received an adequate dose of insecticide. The data obtained in this way closely corresponded to the results of the chemical analysis. For example, the deposit of 120 mg per square metre found over a width of 100 metres treated with the D.C.3 brought about the death of all the flies within a reasonable period of about 50 minutes. As has already been mentioned, with respect to residual effect, leaves taken from the vegetation treated retain the power of killing flies within a normal time interval (less than two hours) for three or four days after the passage of the helicopter, when the product employed has been spread in a normal dose of 11 mg per square metre. With doses of the order of several hundred grams per hectare, however, residual action lasting four weeks can be obtained in the dry season, using fogging alone. This method is clearly too expensive to be employed frequently with such doses. Moreover, the recent appearance on the market of emulsions with particularly pronounced adhesive properties (special resistance to tropical rains) enables the important question of residual action to be solved by aerial spraying and at less cost. For the treatment of a given air space so as to surprise the insect and destroy it away from its refuges, the use of Gesarol NL thermal aerosol is particularly indicated, since in addition to its direct lethal effect it gives a deposit with a short residual action period of three to four days. For wholesale destruction, e.g. of Aëdes aegypti, this method is the most effective. For the monthly decimation of larvae and adults of Anopheles gambiae multiplying in the open, the same aerosol gives surprising results, as will be mentioned further on. Tsetse flies and Simulium are also remarkably sensitive to DDT aerosol. Various disinsecting campaigns were specially directed against Anopheles especially in the coastal region of Banana-Moanda and Leopoldville (Kinsuka).

1. Coastal Region (Banana-Moanda)

As a result of studies in the field, based on the work by Muirhead-Thomson entitled "Mosquito Behaviour", we found that malaria in the coastal region is caused mainly by Anopheles gambiae melas, the concentration of which in the fishermen's huts is unbelievable (30-40 per hut in broad daylight, for example). Cases of pernicious malaria are not uncommon among the village children and the parasite rate among children in the region was 67.9% before the control operations. The adult mosquitos have numerous resting places outside habitations: in bushes, in the marshes, in the hollow trunks of Avicennia, under the dark, shady banks of creeks. Consequently, house spraying might be expected to be at least a partial failure, as already experienced at Kinsuka (we shall return to this point later) and as Muirhead-Thomson had observed elsewhere. On the other hand, the larval breeding places are clearly circumscribed and of limited area, consisting for the most part, if not completely, of _Avicennia_ groves, regularly covered at high tide. The basic idea in the various campaigns was to kill the larvae by DDT fogging or BHC spraying and to kill the insects flying at dawn, when they return to their refuges, or at dusk, when they leave them, as well as to eliminate egg-laying sites by covering them with a layer of residual insecticide. Because of local topography, the danger of reinfestation was limited to the creeks in the estuary of the Congo where the _Rhizophora_ mangrove covers about 40 000 hectares. A more threatening danger was that arising from the Angola bank of the river which, in certain places, is only two and a half kilometres distant, and where the great hurricanes during the rainy season follow a path aiding the mosquitos to cross the bay. In May and June 1953, a first attempt to eradicate _Anopheles_ was made. Treatments were repeated in a sequence so calculated as to exterminate in the breeding places on each occasion, the "descendents" of insects which had escaped the previous treatment. From 4 May to 13 June, the D.C.3 flew 41 hours 15 minutes and a helicopter 23 hours 17 minutes, using in fogging operations 90 827 kg of Gesarol NL containing 17% DDT, and 11 647 kg of Gesarol NL, containing 15% DDT + 2% BHC. After 20 May not a single mosquito could be caught in Banana and we had very great hopes that the _Anopheles_ had completely disappeared when, on the 56th day (16 July) the first mosquito reappeared. From then onwards the increase was overwhelming and during the first 20 days of September 1039 were caught. The campaign had failed! Because of the lack of specialized personnel it had been impossible to enumerate and locate potential breeding places nearby, from which the fresh invasion had taken place. Still more serious, the infestation rate reached a level never attained previously at a comparable period. Very probably the intensive campaign had affected the small mosquito-eating fishes, thus upsetting a valuable biological balance. Another attempt to bring about eradication, which had nearly been achieved, was urgently necessary. A study of the causes of the initial failure gave hopes of a real success. This time the plan of campaign was completely changed, taking into account both the exact distribution of the larval breeding places, located up to the last minute by helicopter reconnaisance flights, and the nature of the products at our disposal. The D.C.3 sprayed 73 000 litres of 4% BHC solution in fuel oil and used

17 900 kg of Gesarol NL for fogging. The helicopters employed 45 000 kg of NL 2 for fogging, concentrating solely on the Avicennia groves (larval breeding places). The campaign took place from 19 October to 14 December, following a time-table based on the tides and comprising four different cycles. The flying time of the D.C.3 was 41 hours 30 minutes and 56 hours in the case of the helicopter, which covered about 1300 hectares. The basic idea was to "clean up" the region on a large scale and to concentrate a large amount of insecticide with a long residual action on the breeding places. Systematic captures of mosquitos were organized at various points in a treated area. It may be said that the region remained practically free from Anopheles from 20 October until the following 10 January, i.e. for 81 days. This result was only obtained thanks to careful surveillance of the periphery, where the first mosquito reappeared on the 24th day after the end of the campaign and where immediate action was taken. Nevertheless, without continual treatment, reinfestation would have occurred just the same. This second attempt at eradication, carried out with ample means over a large area, strengthens us in our belief that, under the rural conditions prevailing in Central Africa, eradication of Anopheles is at present a very hazardous undertaking.

Large-scale campaigns are characterized by:

(1) the consumption of many tons of insecticide;

(2) the need for a very prolonged effort on the part of the pilots;

(3) the development, after a few weeks, of a serious biological lack of balance in favour of mosquito larvae;

(4) inability to prevent an eventual re-invasion from areas left untreated, sometimes at a considerable distance (action of the wind).

Consequently, it was decided to carry out campaigns on a reduced scale, limited to the larval breeding places and repeated every month. Thus every four weeks the helicopter drops about 5000 kg of Gesarol NL on these areas. After treatment restricted to the Avicennia groves and a passage above the villages for imago control, there is an interval of three weeks during which only a few rare Anopheles are captured (five or six in all). Before the next passage of the helicopter, the first hatching out of Anopheles in any number occurs. As we can count on a full week before the females become infective, the helicopter destroys most of them before the plasmodia have had time to develop into sporozoites. The correctness of this reasoning was subsequently confirmed by the fall in the parasite rate among the children of the area, as shown by the following figures:

parasite rate	in	July 1953:	64.8%
"	"	May 1954:	25.2%
"	"	Nov. 1954:	24.9%

Thus, using the aerial method alone, a fall in the parasite rate of the order of 40% was brought about in the coastal region. The failure of attempts to eradicate Anopheles and the success of the method for the monthly reduction of the Anopheles population of the area should be noted. Two other aerial campaigns were launched at Boma and Tshela; the results obtained are still under study. Every four weeks a Health Service helicopter, after treatment of the Kinsuka breeding places, leaves on the circuit Boma-Tshela-Banana-Moanda and return. During this trip the helicopter discharges:

3000	kg of Gesarol	NL	at Boma
6300	"	"	at Tshela
4500	"	"	at Banana-Moanda
9600	"	"	at Leopoldville

It should be remembered that, in addition to Anopheles, the work of the helicopter in these various centres is also directed against Aëdes aegypti, Mansonoïdes, Culicoides, Culex and other biting insects, which are sometimes veritable plagues.

2. Leopoldville Campaign (Kinsuka)

The rapids area at Kinsuka, represents the major breeding place for Anopheles gambiae at Leopoldville. The numerous hollows formed in the rocky banks of the rapids, the stone quarries and brick works, all form breeding places where A. gambiae finds ideal conditions for reproduction. In addition it should be noted that the nature and special position of the terrain results in the majority of these breeding places being inaccessible by land or water. A somewhat unusual situation was found in the Kinsuka sector, since no mosquitos were captured in the houses although there were large numbers of A. gambiae in the larvae breeding places in the midst of which the village is situated. Furthermore, the percentage of children carrying the parasite did not undergo any decrease following the spraying of dwellings with BHC in a concentration of 200 mg of gamma isomer per square metre. This suggested the theory of a resistance due to the behaviour of the insect which, after a blood meal inside or outside the huts, returns to its resting places outside without settling on the walls. The last treatment of the huts took place on 10 September 1952. At the beginning of January 1953, the first adult Anopheles was trapped and the number of captures continually increased. At the beginning of May, the parasite rate was 55%. From May to November, several helicopter campaigns were carried out (Gesarol NL fogging). From 27 May to 29 June, the region was freed from all adult or larval Anopheles in the course of 38 flights totalling 19 hours 32 minutes, although the number of mosquitos reaches a maximum at this time of the year. Unfortunately, re-invasion took place from territories situated to the north of the Congo. The points of penetration were immediately sought out and treated. A campaign was even organized on the French bank of the Congo with the authorization of the F.E.A. authorities. Several campaigns followed one another up to 15 November (77 flights totalling 41 hours flying time). During this period, which is very favourable owing to the rocky banks becoming exposed, 999 breeding places were found in 427 visits, i.e. an average of 2.3 breeding places per visit, whereas immediately before the campaign the average was 13.4 breeding places per visit and in the corresponding period of the previous year the figure reached 23.4 breeding places per visit. The mosquito population had thus been reduced by 90%. At this moment, five months and 20 days after the commencement of the aerial campaign, the parasite rate was 35.5% as against 55% before the campaign and 65% in September 1950 (during the same year, 1950, the parasite rate was 43.6% in April and 60.1% in June). In view of these results: on the one hand, the failure of Anopheles eradication campaigns, on the other, the favourable effect on the parasite rate of the "reduction campaigns" carried out, results also confirmed by those obtained in Moanda-Banana, it was decided to give up the idea of eradication and to apply a monthly treatment plan. This plan aimed at reducing the mosquito population and keeping it down to a number and age level so that its potential infectivity is reduced to the minimum possible under these conditions. Since January 1954, the helicopter has discharged 9600 kg of Gésarol NL each month in this region. The fall in the number of breeding places and of adults captured was remarkable, as was the effect on the parasite rate. In January 1954 the latter was 27.7% and in January 1955, 25.7%. In March and April 1955 no flights took place, since the Government had acquired three helicopters of a more powerful type (Sikorski S.55) and there was an interval while the machines were being assembled and tested. Immediately there was a slight increase in the parasite rate, which was 32.3% in August 1955. Consequently this too, indicated the success of the aerial method applied alone.

CONCLUSIONS

After three years of study, it has been possible to define the limits and possibilities of aerial methods of disinsecting. In our conclusions we shall limit ourselves to the subject of this conference, namely, malaria. Plans of campaign should aim at final eradication only if topographical conditions, biology, the range of flight of the insect, the probable sources of re-invasion and the direction of the prevailing winds all give a satisfactory probability of success. If these requirements are not fulfilled it is useless to use up large tonnages of insecticides in a campaign, only to find a few weeks later a degree of infestation at least equal to that previously observed. Moreover, massive intervention sometimes risks upsetting a biological equilibrium favourable to the aims pursued. The judicious use of helicopters should be based on a number of brief, localized monthly treatments, enabling appreciable results to be obtained with a minimum of expenditure. This method has made it possible to obtain positive results in *Anopheles* control. In certain well-defined cases it may appear, after a thorough preliminary study, that the destruction of the larvae by DDT aerosol using the helicopter gives results where house spraying has been rendered ineffective by the existence of resting places for the adult insects outside the treated dwellings. The larvicidal method by helicopter should therefore not be regarded as a panacea. It is more expensive than house spraying and is indicated where the latter has failed. Although this method may not give, in Anopheles control, the spectacular results obtained against Simulium and the tsetse fly, nevertheless it is in my opinion a valuable auxiliary in malaria control work.