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R. Le Berre, R. Garms, J. B. Davies, J. F. Walsh, B. Philippon, C. G. Johnson, C. F. Hemming, D. J. Lewis, P. O. Odiyo, R. W. Crosskey and J. M. Castel

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# Displacements of *Simulium damnosum* and strategy of control against onchocerciasis

By R. Le Berre,† R. Garms,‡ J. B. Davies,† J. F. Walsh,† and B. Philippon§

† *Programme de lutte contre l'Onchocercose, B.P.* 549, *Ouagadougou, Haute Volta*
‡ *Tropeninstitut, Bernhard-Nocht-Strasse* 74, 2 *Hamburg* 4, *West Germany*
§ *Institut de Recherches sur l'Onchocercose, ORSTOM/OCCGE, B.P.* 1500, *Bouaké, Côte d'Ivoire*

Regular aerial treatment of 14000 km of watercourses has achieved and maintained, over an area of 700000 km$^2$ of West African savannah, a very high degree of control of the larvae of *Simulium damnosum sensu stricto* and *S. sirbanum*, the vectors of onchocerciasis in this area. However, particular and relatively restricted parts of this area, mainly in northern Ivory Coast and neighbouring parts of Upper Volta, experience regular and prolonged reinvasions by parous female vectors, which have already taken blood-meals (and many of them carrying the parasites) and arrive from unknown sources probably hundreds of kilometres away, from directions probably between southwest and north. This reinvasion, now experienced in three successive years, represents the outstanding scientific, epidemiological and logistic problem still facing the WHO Onchocerciasis Control Programme. An outline is presented of the multidisciplinary investigations being undertaken to find a solution.

## 1. Introduction

Onchocerciasis, including river blindness, constitutes a total barrier to the development of the valleys of much of the African savannah (Le Berre 1978), and no safe and effective method of mass treatment is yet available. Control therefore depends on the destruction of the vectors, all belonging to the family Simuliidae.

In west and central Africa, the role of *Simulium damnosum* Theobald 1903 as a vector was established by Blacklock (1926). *S. damnosum sensu lato* is now known to comprise a number of species differing in bio-ecological and epidemiological characters and in geographical distribution (Vajimé & Dunbar 1975; Quillévéré & Pendriez 1975). A general distinction can be made between those species confined principally to the forest areas (*S. sanctipauli* V. & D., *S. yahense* V. & D., and *S. soubrense* V. & D.) and those belonging essentially to the savannahs (*S. damnosum* Th. s.s., *S. sirbanum* V. & D.); *S. squamosum* End. exists as apparently isolated populations distributed through the two bioclimatic zones. In this paper the more general term of *S. damnosum* s.l. is used for convenience wherever appropriate.

*S. damnosum* s.l. has two fundamental characteristics which determine the strategy and tactics used in its control. First, the requirements of the larvae, while varying from one species to another (Quillévéré *et al.* 1977), are exacting, particularly for food (Le Berre 1966, p. 162), as shown by their restricted spatial distribution, which makes possible the precise location at all seasons of the *gîtes* (sites of larval populations, past or present) of a species. It is therefore possible by very detailed survey at different times of year to plan and put into effect a campaign specifically aimed at destroying all larval populations in a given area.



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This favourable factor is, however, offset by the power of flight of the females, whose potential for long-distance displacement has been known in general terms since the original studies (Austen 1909). Le Berre (1966, pp. 72–107) has reviewed the earlier work and put on record his own observations on the displacement of *S. damnosum*. Subsequent work has included studies of recapture of marked females (Haüsermann 1969; Disney 1970; Thompson *et al.* 1972), of the dispersal of females as a function of age (Garms 1973; Duke 1975), and the timing and manner of repopulation of temporary habitats (Le Berre & Balay 1967). This last study showed morphometrically that females captured at the beginning of the wet season (June) did not belong to the same population as those captured in the same area of Upper Volta at the time of the last river flow in the preceding dry season (January). As the first *gîtes* around the study region to be occupied at the beginning of the rains were more than 150 km distant, this study provided proof of large-scale migration by *S. damnosum* over such distances.

These contrasting attributes of the larvae and the adults (narrowly localized versus widely dispersed) have dominated the strategy and tactics of campaigns against *S. damnosum*. On tactics, the dispersal of the females has not allowed control to be directed at them: apart from a campaign in the Kinshasa area (Wanson *et al.* 1949), where it was realized subsequently that the effect of the treatment was also larvicidal. On the other hand, the localization of the pre-imaginal *gîtes* gives control campaigns against the larvae a good chance of success.

Concerning strategy, the flight performance of the females and the possibilities of their immigration into treated zones preclude eradicating the species at any single individual focus, except for populations that are very isolated both geographically and specifically (e.g. *S. squamosum* in Upper Volta); thus a vast area must be treated to reduce, at least in its centre, the consequences of possible reinvasions, and treatments must be continued over a very long period (15–20 years) to achieve a sufficient reduction in the parasite population carried by man.

Earlier campaigns all had the defect of being too limited in time and space; with perhaps only one exception (Farako, see below), the inadequate extent of the treated areas has resulted in transmission, by immigrant female flies, being maintained at too high a level to be acceptable for resettlement of the deserted valleys.

The Farako region of Mali is a limited area which was treated for sufficiently long (13 years) for a considerable improvement in health to be registered by the parasitologists and opthalmologists (Prost 1977). The success obtained there, together with improved understanding of the biology and ecology of the vector and of the dynamics of transmission of the parasite, and the success of appropriate new control methods (new insecticides; survey and treatment by air) made it possible to envisage a campaign meeting all these criteria, particularly of time and space, to reduce the consequences of onchocerciasis for the human communities of the savannah. The future development of these communities is critically dependent on the exploitation of these valleys. Following an initial meeting at Tunis in 1968, the strategy and tactics – the region to be selected for treatment and the methods to be employed – were worked out in detail during the following five years, and the programme was finalized in 1973 (Anon. 1973).

## 3. The WHO onchocerciasis control programme

### (*a*) *Outline description of the programme*

The programme covers 700000 km² of the savannah zones of the seven west African states of Benin, Ghana, Ivory Coast, Mali, Niger, Togo and Upper Volta, with 14000 km of watercourses

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treated each week in the rainy season, within an area bounded in the north by the limit of distribution of the vector and the disease, and in the south by Lake Volta in Ghana and Lake Kossou in Ivory Coast. Given the longevity of the parasite in man (15 years for the adult filaria, two years for the microfilaria), the impossibility of carrying out a campaign of medical treatment, and the possibility of reinvasion into areas subjected to larval control, the programme has been envisaged for a duration of 20 years.

(i) *Treatments*

The treatments are supervised and planned by a group of entomologists and operations officers, and are sub-contracted to an aircraft operating company using eight helicopters and two aeroplanes to apply the larvicide; aeroplanes treat the larger rivers, and helicopters the narrower watercourses and those with a smaller discharge. Temephos (Abate(R) WHO 786) is used, as the only insecticide combining high toxicity against *S. damnosum* with the lowest known toxicity to other associated fauna. Applications are made upstream from each *gîte* or series of *gîtes*, on a weekly basis. They are suspended when a given region is shown to have been temporarily cleared.

(ii) *Entomological evaluation*

This evaluation is coordinated and supervised by the entomologists, working through seven sector chiefs and the technicians in charge of 23 sub-sectors covering the programme area, with extensive support staff, transport and equipment. The efficiency and timeliness of the treatments is initially assessed by periodical examination of the *gîtes*. Then, emphasis is particularly directed to detecting residual populations of females of *Simulium*, which are captured using human bait – the only technique currently providing direct and adequate evidence of the presence and scale of residual populations. Dissection of captured females, to determine the age of populations, provides a further indication of the possible inadequacy or absence of treatment of an active *gîte*. It also permits a precise evaluation of the potential rate of transmission which has existed for each place over, say, a 12 month period: the subject of many studies to define a level acceptable for human populations.

The results of the *gîtes*, the capture and dissection of females, and the discharge rate of the watercourse at each hydrological station are transmitted weekly by radio (19 stations) to the main operational bases at Bobo-Dioulasso and Ouagadougou. Evaluations and control operations can thus be planned and modified as necessary for the following week. The entomologists and technicians use the programme's aircraft as necessary to visit and inspect suspect areas.

(iii) *Hydrobiological evaluation*

The evaluation of the effect of larvicides on the environment, particularly on the aquatic fauna, is the responsibility of two groups of hydrobiologists, financed under the programme but scientifically independent. It is undertaken by the ORSTOM Centre of Hydrobiology (at Bouaké) – covering Ivory Coast, Mali and Upper Volta, by the Institute of Aquatic Biology (at Achimota) – in Ghana and Togo, and by an independent research worker in Benin and Niger.

(iv) *Medical evaluation*

Medical assessments are made by an epidemiological unit comprising epidemiologists, parasitologists and ophthalmologists. Initial surveys have been made to establish the base level

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of the disease (prevalence and severity), and the unit will periodically re-visit the selected villages to determine the effectiveness of the entomological campaign.

(v) *Other aspects*

The headquarters of the programme is based at Ouagadougou, with the administrative unit. A third unit is responsible for financial matters and for maintaining liaison with the various governments, through the officers in charge of their development plans.

The programme also provides for relevant applied research (entomology, insecticides, chemotherapy, hydrobiology) at a number of independent institutes and research units elsewhere. The ORSTOM/OCCGE Institute of Research on Onchocerciasis, at Bouaké, is responsible for training entomologists and technicians.

(*b*) *Execution of the programme*

Operations have been undertaken according to plan. In phase I, larval control operations began in February 1975 in northeast Ivory Coast, west Upper Volta, southeast Mali and northwest Ghana. In phase II treatments were extended in January 1976 to central Upper Volta and north Ghana. In phase III, areas of south Mali, northwest Ivory Coast, north Togo, north Benin, southwest Niger and east Upper Volta have also been treated as from March 1977.

Treatments have been carried out regularly, satisfactorily and wherever they were required, with only such interruptions as have been planned by the entomologists to follow satisfactory results in particular areas. Entomological evaluation functions satisfactorily, and the network has been found to reveal very speedily any shortcomings of treatment. The watching brief on the environment is maintained as planned; the insecticide treatments have had no drastic effect on the invertebrate fauna, and no effects have been detected on the fish. The unit for epidemiological assessment is ahead of schedule, and has been able to examine a larger population sample than expected.

## 3. Results to date

Except for the areas subject to reinvasion (§ 3*a*), the numbers of *Simulium* captured have always been very low, indeed zero at many places, with an amount of residual transmission sufficiently low to be acceptable for resettling human populations in the valleys. This satisfactory result can clearly be expected to be maintained, and indeed improved upon at certain points.

Failures of treatment have been very localized in both space and time, their causes being: occasional errors in application; insufficient dosage, generally due to a sudden increase in flow rate of the watercourse; inevitable delays of a few days in treatment when temporary streams start flowing at the beginning of the rains; and difficulties in correctly distributing the insecticide above certain *gîtes*, natural or articifical (weirs, crossings), especially during the dry season. These defects were quickly betrayed by the appearance of local populations of *Simulium* and by recrudescence of transmission, and were very soon rectified.

Considering the extent of the success of the methods and techniques employed, and especially as the susceptibility of the *Simulium* populations to Abate has remained unchanged in those areas where treatments had been deliberately discontinued, reasonable optimism may be expressed for the outcome of the campaign.



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### (a) *The reinvasion problem*

'Occasionally, large number of Simuliids suddenly invade a formerly untroubled area.' This sentence by Wellington (1974) about north American simuliids reads prophetically, having been written on the eve of the first year of our campaign.

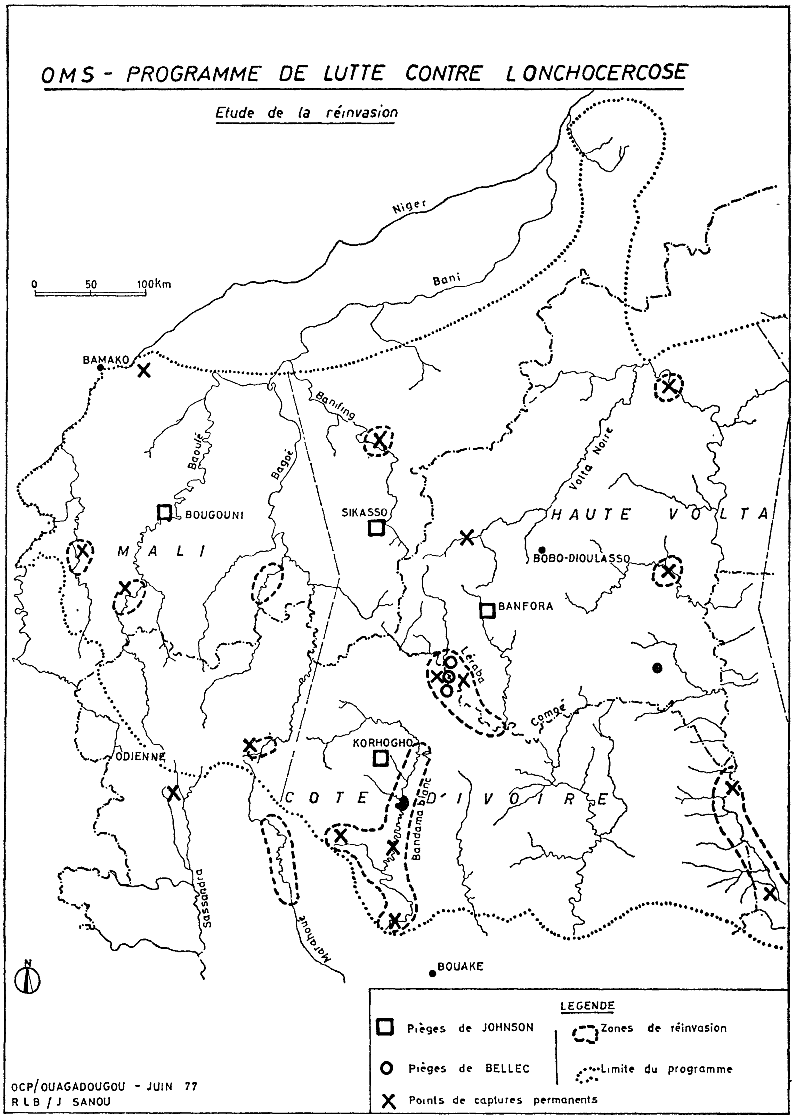


FIGURE 1.

(i) *Reinvasion* 1975

Following an initial period of successful control, when throughout the phase I area the numbers of females captured had been extremely small or zero, the *Simulium* populations increased considerably in certain areas from late April 1975. Apart from a few isolated places in the Black Volta basin, this resurgence of females remained localized along the Bandama and Léraba (figure 1); it was evident throughout the rainy season from May to September, and only ceased, spontaneously, in October. The programme's routine monitoring (table 1) provided no explanation of this increase in *Simulium* populations; from the outset, the numerous

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surveys undertaken could only confirm the effectiveness of the larval control in this area (as would indeed have been expected from the results of the F.E.D. campaign, Le Berre 1968), apart from a few failures which were very localized and temporary. This led to the inference that the treated areas were being reinvaded by immigrant females. Magor *et al.* (1975) concluded that: 'Results of the biogeographical studies (on one 1975 reinvasion and two earlier case-studies) show a close association between the passage of zones of convergence across an area and the appearance of flies', but considered that the data then available were insufficient to provide any further explanation.

In view of the entomological and epidemiological importance of reinvasion, for these immigrant females gave a high level of transmission, a special research programme was prepared during the dry season 1975–6 (see table 1), to bring to bear on the problem the best available expertise, methods and techniques.

TABLE 1. TECHNIQUES D'ÉTUDE DES REINVASIONS

| Année | captures normales | captures quotidiennes: intérieur zone | captures quotidiennes: extérieur zone | speciation sur larves | speciation sur femelles | controle possibilité transmission locale | prospection gîtes intérieur zone traitée | prospection extérieur zone traitée | traitement phase III Ouest | traitement sources exterieures potentielles | avion météo piègeage (Rainey) | X-ray fluouresence (Bennett) | pièges suction (Johnson) | pièges plaques (Bellec) | météo synoptique | météo locale Léraba |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1975 | + | − | − | + | − | − | + | + | − | − | − | − | − | + | + | + |
| 1976 | + | + | − | + | + | + | + | + | − | Bandama aval | + | + | − | + | + | + |
| 1977 | + | + | + | + | + | − | + | + | + | Sassandra amont | − | + | + | + | + | + |

(ii) *Reinvasion* 1976

Reinvasion indeed occurred in 1976, in the same areas as before and, to within a few days, on the same dates. The special research programme undertaken with the active collaboration of numerous specialists and institutes of research, mainly the ORSTOM/OCCGE Institute of Research on Onchocerciasis at Bouaké, was actively coordinated and its results analysed by Garms (1976), as summarized below.

The Simuliids reappeared after treatment from mid April along the Léraba and Bandama, and, during the wet season, at a few isolated points in the Black Volta basin. This recrudescence continued throughout the wet season, decreasing only in September, and disappearing from October onwards. The systematic surveys of the *gîtes* on all the watercourses within the programme region again recorded negative findings, with exceptions which were rare and on a scale much too small to explain the phenomenon. Captures made daily at a number of places (figure 1) showed that females were captured only near the rivers, and that they did not disperse through the surrounding areas, contrary to earlier observations in this area (Le Berre 1966, p. 100). The females appeared in a number of successive waves between May and the end of August, with peaks on or about the same dates at widely separated places (170–350 km apart), for which 'The most likely explanation is the regular transportation of large numbers of



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flies by wind-systems into the Project area' (Garms, 1976). This interpretation was supported by the findings of Rainey *et al.* (1976).

From the onset of reinvasion, as in 1975, a very high percentage of females was shown to be parous (97% in May, 100% in July and August), i.e. the females had already taken one or two blood-meals before leaving their source areas or during migration. The rate of infection of the females by *Onchocerca volvulus* was very high (5–15% found infected at the Léraba). As a number of the arrival areas are now deserted by man, this means that the females will have been infected before departure or en route, i.e. 'the Programme area is not reinvaded only by the vector but also by the parasite ...' (Garms 1976). These observations again are inconsistent with populations originating locally but confirm that the area is being reinvaded. Reinvading females fed on infected subjects in the arrival area have shown that they can retransmit normally the parasites ingested there, as would be expected from these species (*S, sirbanum*, *S. damnosum* s.s.). Research on other parasites as natural markers, undertaken inside and outside the programme area, has not thrown any further light on reinvasion. At the beginning of the season, first generation larvae from eggs from large samples of newly caught reinvading females were reared in the laboratory (by Raybould) until their cytotype could be determined; all were found (by Quillévéré & Vajimé) to belong to the two savannah species *S. damnosum* s.s. and *S. sirbanum*. Soon after the start of the 1976 reinvasion, Quillévéré *et al.* (1976) succeeded in developing a method of distinguishing the different species of the *S. damnosum* complex taxonomically, by direct examination of certain morphological characters of the females (antennae, maxillary teeth). This break-through was put to immediate use, and in examination of large numbers of specimens has confirmed and extended the evidence of the cytological identifications: the great majority of the immigrant females were of the two savannah species, sometimes including also *S. soubrense*. Finally, the method of Lewis (1965) and Lewis & Duke (1966), based on the size and colour of the individuals, has also been used; it has shown that the simuliids of the forest zone of the lower Bandama are different from the immigrant females captured further north. Independent confirmation on this point was provided by experimental control on the lower Bandama, a forest area of high production of simuliids. This had been suspected from 1975 as a potential source area, and was successfully treated during June 1976. The *Simulium* density, which was high before treatment began (1000 females per day per man), was rapidly reduced to less than 5 females per day per man and remained at this level for some weeks – but without any noticeable effect on the continuing reinvasion of the areas immediately to the north. A southern origin for these immigrant females may therefore be rejected, confirming the implications of the cytotaxonomic evidence.

X-ray fluorescence spectroscopy, as developed by Bennett (D'Auria & Bennett 1975), permits characterization, in terms of certain chemical elements ('fingerprinting'), of populations, and indeed individuals, originating from different environments. Comparing samples (larvae and newly emerged females) from certain suspect zones outside the programme area with those from immigrant females has shown that there is a good correlation between larvae and adults from the same locality; and that there is a correlation between immigrant females on the Léraba and on the Bandama, suggesting common origins, but which may include several sources probably to the southwest in April and May, and to the west and northwest from June onwards (analyses by J. B. D.).

Winds over the areas of reinvasion were studied in detail during August in relation to possible displacements of the vectors, by using a research aircraft equipped for precision wind finding,

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by a Doppler navigation system, as well as for insect trapping (Rainey *et al.* 1976). The wind-fields encountered were found to range from undisturbed and near uniform southwest monsoon flow with fair weather, to less settled winds from other quarters, often with belts of storms associated with wind shifts, which on five occasions were at squall-lines such as have been suggested as possible agents of dispersal for *Simulium* (Marr 1971). A preliminary examination of the routine synoptic meteorological charts at Ouagadougou airport, in relation to the daily *Simulium* catches for April–August 1976, had directed attention to the temporary occurrence of extensive areas of northerly to northwesterly winds one to four days before a number, though not all, of the peak *Simulium* catches recorded by Garms (1976). These results provided general support for the suggestion that the reinvading females were probably originating within the sector from southwest round to north.

The only trapping in 1976 was with the Cranfield aircraft trap (Rainey *et al.* 1976). In samples totalling a million cubic metres of air, some 1500 insects were caught, including five Simuliids, but none of them belonged to the *S. damnosum* complex (Rainey *et al.* 1977).

(iii) *Reinvasion* 1977

April 1977 was particularly favourable for the study of reinvasion, as many watercourses that might have constituted sources or stopping places for *Simulium* had dried up, and the treatment of the area of phase III west, from March 1977, suppressed numerous other potential sources that had been suspected the previous year. Therefore the very small number of females being captured within the treated area (most of the catching points gave nil returns) enabled the first signs of reinvasion to be detected very readily, notably at the Léraba bridge where no *Simulium* had been detected for several weeks.

Further, methods and techniques already employed were augmented by suction-traps, made available by C.O.P.R., and set up by Dr Johnson at four sites (figure 1); by attraction-plate traps, developed by Bellec (1976) in the course of earlier years, and used at the Léraba bridge; by the installation of a meteorological station on the Léraba, where reinvasion is always shown up most distinctly; and by the extension of permanent capture points to beyond the treated area.

On 10 June 1977 the situation was as follows: reinvasion had started at the end of April on the Bandama and the Léraba, when the two nearest breeding areas were the Sassandra and the lower rapids of the Marahoué. The treatments of phase III area had revealed that certain localities in southern Mali and northwest Ivory Coast, previously suspect, were equally subject to reinvasion; therefore the phase III area can no longer be considered as a source, but is an area receiving reinvasion. The first immigrant females had been captured on the Bellec plates; they were mainly gravid or parous (only 4 nulliparous out of 30 females captured during the first five days). The first *Simulium* was not captured on man until two days after the first Bellec catch. The females were again mainly of the two savannah species, although *S. soubrense* and *S. sanctipauli* were also occasionally found. The initial results from the suction-traps are not yet in hand.

(iv) *Reinvasion findings and further work*

The three years of study have shown that reinvasion occurs more widely than had initially appeared, in an arc from southwest Mali through the upper basins of the Baoulé, Bagoé, Léraba and Bandama to the Bandama above Lake Kossou; beyond this arc to the north and

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northeast there are local appearances of short duration, at the times of bigger rises in the number of females captured inside the main reinvasion area. Near the centre of this area, i.e. in the west and southwest of the treated zone, is a band concentric with the first, where a significant percentage of nulliparous females has been captured. The immigrant females originate in the savannah zone, to the west and northwest of the programme area, which could implicate the states of Ivory Coast, Guinea, Mali and Senegal.

In view of their geographical position, their high productivity, and the cytotypes of the populations that live there, the upper basins of the Sassandra and the Marahoué are highly suspect as possible sources, of which experimental treatment has been planned to begin at the end of June 1977. By the end of the experimental treatments of the Marahoué and Sassandra, in early August 1977, there had indeed been a great reduction in the number of flies found in the re-invaded areas of the Bandama, Bou and Léraba rivers, and there was also a decline on the upper Bagoué, but not in the Baoulé and Sankarané valleys of Mali. If the treatment has no great effect on the immigration, implying that the remaining flies come from areas further west and logistically inaccessible, it is planned to use techniques similar to those employed against riverine *Glossina*, to treat the gallery forest of the arrival areas, inside which the Simuliid females are envisaged as becoming sedentary.

It is impossible to mention all those who have participated in this team work, but we are very happy to thank: the entomologists and technicians of the Vector Control Unit of the Regional Programme, who have borne the brunt of a problem which has developed in their areas of work, particularly R. Sawadogo and T. Awoto, respectively heads of the subsectors of Banfora and Korhogo; also J. Henderickx and H. Orain in the field of surveys and logistic support; the entomologists and technicians of the Institute of Research on Onchocerciasis (ORSTOM/OCCGE) at Bouaké, particularly D. Quillévéré and C. Bellec for their help and constant collaboration; our colleagues J. Raybould and C. Vajimé who have reared the *S. damnosum* in the laboratory, and for the part they have played in taxonomically characterizing the immigrant females; R. C. Rainey, F.R.S., M. Haggis, C. G. Johnson and P. T. Haskell for their collaboration; Mr C. Baldry, agrometeorologist.

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## *Discussion*

C. G. Johnson (Chairman; *formerly Head of Entomology Department, Rothamsted Experimental Station, Hertfordshire*). The intensive treatment of that vast area of rivers and streams seems to be a daunting prospect, almost an unbelievable achievement, I think, until one sees for oneself that it is really practicable. This is, of course, quite apart from the problems of reinvasion by flies from beyond the boundaries of the treated areas.

C. F. Hemming (*C.O.P.R., London*). What sort of distances are now envisaged for the migrations of *Simulium*?

R. Le Berre. Our earlier work in Upper Volta with Balay had provided morphometric evidence that the flies were able to migrate over distances of more than 150 km. Now, if reinvading flies are coming from the Marahoué, they have to fly about 150 km; but, at the beginning of the reinvasion both in 1976 and 1977, they could not have been coming from the Marahoué because this river was then still dry and accordingly unproductive. If they were then coming from the Sassandra that would have been about 300 km.

D. J. Lewis (*British Museum (Natural History), London*). Dr Le Berre's very clear explanation of reinvasion makes one think about the future; is it possible to say anything about the policy of control in 20 years time?



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R. Le Berre. The long term aim of this programme is to reduce the worm population in the human population, to establish a new equilibrium between the human population and the environment. A good example is Bamako, the capital of Mali, which is situated on a very big breeding site of *Simulium damnosum* where there is a huge transmission. A village of 300 inhabitants could not exist there because this transmission would be too much for these poor 300 people; but Bamako is 300 000 people, and everyone is taking just a small part of this transmission. What we want to do is to rescue the people in the valleys, by reducing the blackfly population and subsequently reducing the parasite population, to allow the people to go back and to be strong against the blackflies and maybe against the transmission of the parasite. But I would say that 20 years is a first step.

P. O. Odiyo (*East African Agriculture and Forestry Research Organization*, *Nairobi*, *Kenya*). What is the breakdown of the life-cycle of the *Simulium*?

R. Le Berre. The egg hatches in one or two days, and the larva develops in 8–12 days according to the water temperature and the quantity of food. The pupa lasts about 3 days, and the female lives about a month. The gonotrophic cycle is about 5 days, varying with air temperature.

R. W. Crosskey (*British Museum* (*Natural History*) *London*). As the chairman has said, this scheme in West Africa is one of tremendous audacity when you consider the range – virtually all the way from the borders of Guinea to the borders of Nigeria – and it makes one wonder what the lessons are going to be from it if onchocerciasis control is to be extended to other parts of savannah Africa. I would like to ask Dr Le Berre, firstly, what the rationale was for the particular areas covered in the three successive phases of the programme, and, secondly, whether he can already pinpoint any new aspects of strategy that would now have to be considered if we were to move into, say, southern Sudan and start onchocerciasis control there.

R. Le Berre. There was nothing very special about the rationale for the phase areas. They were selected, first, according to the availability of people, particularly entomologists, and technicians; second, on the knowledge we had of the disease and, mainly, of the distribution of the vector during the different seasons of the year; and, third, by considering a reasonable size for the area of each successive phase. We had begun in 1966 with the Common Market F.E.D. campaign, covering 60 000 $km^2$, and we did not want to go directly to the final 700 000 $km^2$, so we made the F.E.D. area the nucleus of phase I. Phase II dealt with northern Ghana and central Upper Volta, where also we had good knowledge of the vector and of the distribution of the disease. In phase III we extended into Mali, northwest Ivory Coast, Togo, Benin, Niger and east Upper Volta, where the situation was only very poorly known when we started. The second question is on the strategy we may now have to use in dealing for example with this Bahr el Ghazal focus in the southern Sudan. I think the first thing is to consider with our friends the meteorologists the possibilities in that area for reinvasion, of which we are learning a lot in this programme; and I think we should never be able to control the disease in the south Sudan without the cooperation of Uganda, the Central African Empire and Zaire. In planning the strategy and tactics of a programme like that we can now go faster and faster. As you remember, we used to spend weeks and months and years along the rivers trying to find the breeding sites on foot. Now we can do that in a very few hours by helicopter; we can land, find *damnosum* or not, and plot the breeding sites on the map. We can also plan the treatment phase much better. Back in 1969–70, for example, treating the river Léraba by land and boat, by four big teams

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with very good technicians, boats and outboard motors, took 5–7 days; now we can do the same thing in $2\frac{1}{2}$ h. It's cheaper and faster, and we can operate at any time, which we could not do before.

J. M. Castel (*OCLALAV, Dakar, Senegal*). The University of Dakar is publishing a new climatological atlas of West Africa containing much information which is likely to be important for onchocerciasis control, such as monthly maps of wind systems, showing for example the inter-tropical front across the Guinea area in April, and with April/May maps of storm days.

C. G. Johnson. Reinvasion and the aerial transport of flies, in relation to the movements of the Inter-Tropical Front, are I know very much in the minds of Dr Le Berre and his colleagues. This year (1977) an attempt was made, in Upper Volta and Mali, to monitor airborne flies with suction traps, sited well away from breeding places: that is to say flies in transit, as distinct from those already arrived and caught at biting sites some time later. All ten traps together sampled nearly $10^6$ cubic metres of air per day. They caught over 3000 *Simulium*, of several species, in five months operating, but among them only one *S. damnosum*. This demonstrates the extremely low volume density of this species (though the total numbers may be great) in areas on migration routes but away from breeding places. The curves for daily suction-trap catches of the other species of *Simulium* were comparable to those of *damnosum* caught biting. However, from May to September, when invading flies were most numerous, the I.T.F. had moved well to the north and prevailing winds were fairly constant from the south to southwest sectors; fluctuations in numbers of flies seem on first inspection to bear little relation to relatively minor changes in wind direction, and the movement of the front then seemed of little importance for these localities. This was not so in the very early stages of invasion when the front was passing over. The relation between the movements of flies and the wind-fields over the areas concerned is most certainly of the utmost importance, and I know continues to occupy the attention of the entomologists concerned with the programme.



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