Tropenmed. Parasit. 30 (1979) 328–344

Entomological Aspects of the First Five Years of the Onchocerciasis Control Programme in the Volta River Basin

J.F. Walsh, J.B. Davies, R. Le Berre

World Health Organization, Onchocerciasis Control Programme, Ouagadougou, Haute Volta, West Africa (Programme Director: Mr Marc Ls. Bazin)

Summary

The history and structure of the WHO Onchocerciasis Control Programme in the Volta River Basin are described. An outline of the vector control operations is given, and the techniques and organisation of the entomological evaluation network are described in detail.

During the course of the evaluation and related studies undertaken between November 1974 and October 1978 almost 1.2 million *S. damnosum* females have been taken in over 52,000 man days of catching, and 674,000 flies were dissected. An assessment based on this effort using Annual Biting Rates and Annual Transmission Potentials shows that the transmission of *O. volvulus* has been reduced to below a defined maximum permissible level over most of the central part of the Programme Area. The difficulties encountered in the remainder, and at certain problem sites are outlined and relevant data given.

The benefits to be expected from extending the area further southwards and the possibilities of later reductions in control activity are discussed.

Entomologische Aspekte der ersten fünf Jahre des Onchocercosebekämpfungsprojekts im Voltabecken Westafrikas

Die Geschichte und die Organisation des Onchocercosebekämpfungsprojekts der Weltgesundheitsorganisation im Voltabecken in Westafrika werden beschrieben, ein Überblick über die Maßnahmen zur Überträgerbekämpfung gegeben und die Methoden und Ergebnisse der entomologischen Evaluierung detailliert geschildert.

Für die Beurteilung der Bekämpfungsergebnisse, die Berechnung der jährlichen Mückendichten und des Übertragungspotentials wurden von November 1974 bis Oktober 1978 in mehr als 52000 Ganztagsfängen fast 1,2 Millionen Weibchen von *Simulium damnosum* gefangen, von denen 674000 untersucht wurden. Die Ergebnisse zeigen, daß die Übertragung im größten Teil des Projektgebietes unter die als vertretbar angesehenen Höchstwerte gesenkt werden konnte. Auf Schwierigkeiten, die sich in einigen Gebieten ergaben, wird eingegangen. Die Vorteile, die eine Ausweitung des Projektgebietes nach Süden erbringen würden sowie die Möglichkeiten, die Bekämpfungsmaßnahmen später einzuschränken, werden diskutiert.

Introduction

In 1926 Blacklock discovered that in West Africa the blackfly *Simulium damnosum** was the vector of *Onchocerca volvulus*, the causative organism of human onchocerciasis (Blacklock 1926a, b). Since that time, evidence of the importance of the disease has been rapidly accuring. Some thirty years ago, chemotherapeutic agents active against *O. volvulus* became available but have so far proved too dangerous to use in mass campaigns. At about the same time the development of chlorinated hydrocarbon insecticides revolutionised the prospects for insect control. Following Fairchild and Barreda's (1945) demonstration that DDT, when applied at very low dosage rates directly into water courses, was extremely effective in killing *Simulium* larvae, numerous *Simulium* control schemes were executed in Africa in the late 1940s and 1950s, the most notable being the control of *Simulium damnosum* on the Congo River at Leopoldville (Kinshasa) (Wanson et al. 1949) and the outstanding campaign waged in Kenya against *Simulium neavei* which resulted in its eradication from the country (McMahon et al. 1958).

*In this paper "*S. damnosum*" is used to denote unspecified species of the *S. damnosum* complex occurring in West Africa, unless the suffix s. str. is used.

0303–4208/79 1500–0328 $ 03.00

In West Africa, where onchocerciasis is widespread and frequently a serious problem, the first attempt at eradication of the vector was made in 1955 at Mayo Kebbi, Chad, but did not succeed (Taufflieb 1955). At Abuja in Nigeria, attempts were made, using a DDT larvicide, to control *S. damnosum* in an area forming part of a much larger untreated focus. A great reduction in vector populations was achieved for several years but the epidemiological results proved disappointing (Davies et al. 1962, Davies 1968). Also in Nigeria a fairly large area was brought under control to protect the work-force engaged on the Kainji hydro-electric project; despite the regular influx of large numbers of *S. damnosum* (Hitchen and Goiny 1966) the limited objectives of the campaign were achieved (Walsh 1970).

Several pilot projects were undertaken in Upper Volta, Ivory Coast and Mali (Le Berre et al. 1965, Le Berre 1968) culminating in an important vector control scheme in the Farako region of eastern Mali which greatly reduced the numbers of the vector and resulted in a highly significant dimunition in the prevalence and severity of onchocerciasis in the local population (Prost 1977, Thylefors and Rolland 1977).

These and other attempts at vector control together with biological investigations (especially Crosskey 1954, Le Berre 1966, Lewis 1957 and 1960, Ovazza et al. 1965 a, b) led to an increased awareness of the extent of the problem and the difficulties in achieving any lasting improvement by means of vector control.

In 1968, USAID sponsored a meeting in Tunis to discuss the feasibility of onchocerciasis control (Joint USAID/OCCGE/WHO Technical Meeting on the Feasibility of Onchocerciasis Control, WHO/ONCHO/69.75, unpublished mimeographed document pp. 64). This meeting concluded that control was technically feasible, and that the chances of obtaining successful and lasting effects would be greatest if the control was carried out in ecological zones that were sufficiently large to obviate the need for continuous protection of the whole area against reinvasion by the blackfly vector. The meeting further suggested that the area centred on the densely populated headwaters of the Volta Basin would offer the greatest prospect of success, owing mainly to pre-existing knowledge of the biology and distribution of the vector, and the epidemiology of the disease together with the existence of on-going small control schemes. This basic idea had been put forward by Waddy in a working document in 1963 but was not formally published until 1969 (Waddy 1969).

The Tunis meeting led to the establishment by WHO of a mission (the PAG Mission) charged with the task of preparing a comprehensive plan for onchocerciasis control. In late 1973, the report of this Mission* was submitted to a conference of participating countries, potential donors and the sponsoring agencies (FAO, UNDP, the World Bank and WHO). The operational plans and budget were approved, an Onchocerciasis Fund managed by the World Bank was established, and WHO was asked to assume the role of executing agency.

Description of the Area

The original area chosen for the OCP (Fig. 1) was almost entirely located between latitudes 8° and 15°N and longitudes 8°W and 4°E, and covered about 654,000 km² within the savanna belt of West Africa, most of it being in the Sudan and Guinea Savanna vegetation zones**. The heart of the Programme area included the whole of the Volta River Basin which was protected to West and East by the incorporation of the northward flowing tributaries of the Niger system lying between the north-eastward flowing course of the Niger itself at Bamako and the south-eastward flowing

---

*Onchocerciasis control in the Volta River Basin Area (Report of the Preparatory Assistance Mission to the Governments of Dahomey, Ghana, Ivory Coast, Mali, Niger, Togo and Upper Volta) OCP/73.1, WHO Geneva, mimeographed, v + 86 pp., with annexes.

**The terms for vegetation zones used here are the common ones of Sahel, Sudan Savanna, Northern and Southern Guinea Savanna as used by Nielsen (1965). These correspond to the terms Wooded Steppe, Dry Savanna, *Isoberlinia* Savanna and Relatively Moist Woodlands used by Aubreville et al. (1958).

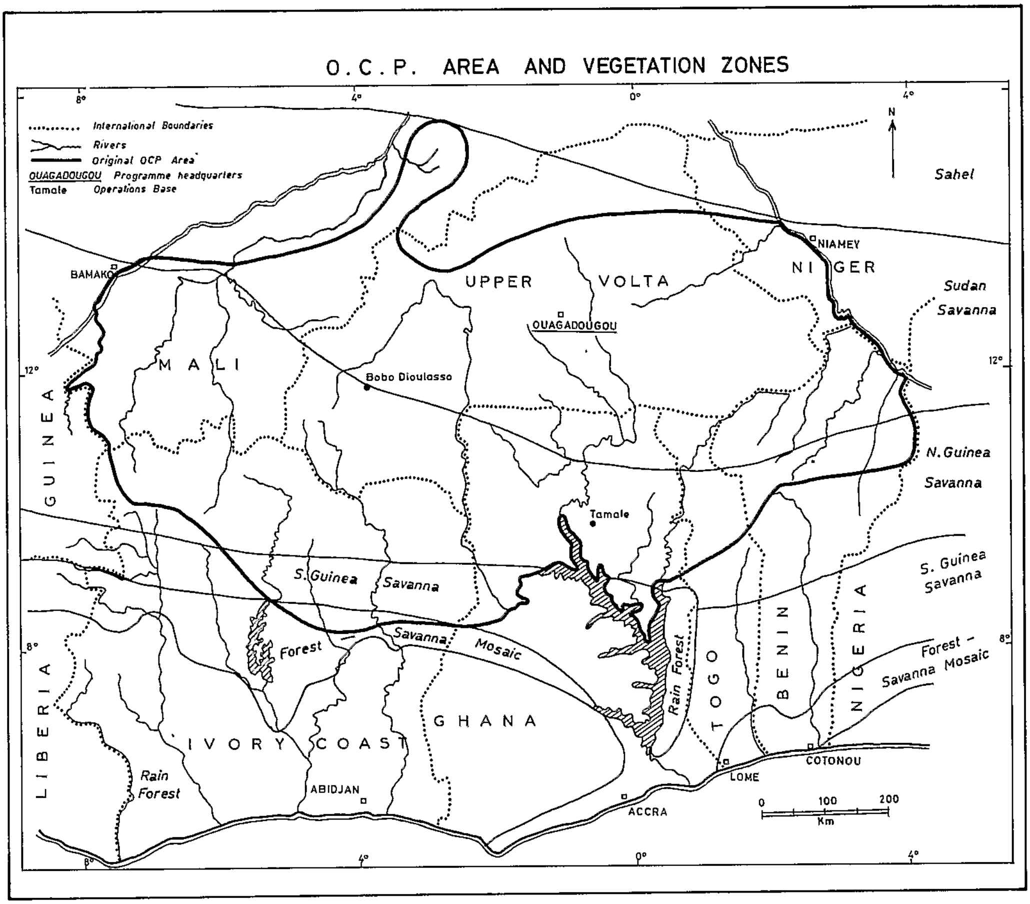

Fig. 1 The location of the Onchocerciasis Control Programme Area in West Africa in relation to the main vegetation zones

course at Niamey. In the western half of the Programme area, were included the savanna zone portions of the Komoé and Bandama systems which flow south directly into the Atlantic Ocean. Rivers, other than the Volta itself, which flow directly into the Atlantic Ocean through Ghana, Togo and Benin were excluded.

The northern boundary was fixed at the natural northern limits of the disease and its vector. The southern boundary was set to take advantage of the Kossou and Volta man-made lakes and was intended, at least in the central area, to incorporate the savanna zones where the disease was most severe. It was believed that flies inhabiting forest areas to the south would not prove capable of invading the savanna. To east and west the boundaries had no ecological merit and were chosen for administrative and political reasons.

The average rainfall of the area varies between about 500 mm in the north and 1300 mm in the south with considerable variations from year to year (Fig. 2). The rainfall pattern is markedly seasonal and very little rain falls within the OCP area from November to March; in the more northerly parts of the area the dry season lasts for at least seven months. The rainfall pattern inevitably influences the hydrological situation to a great extent but this is

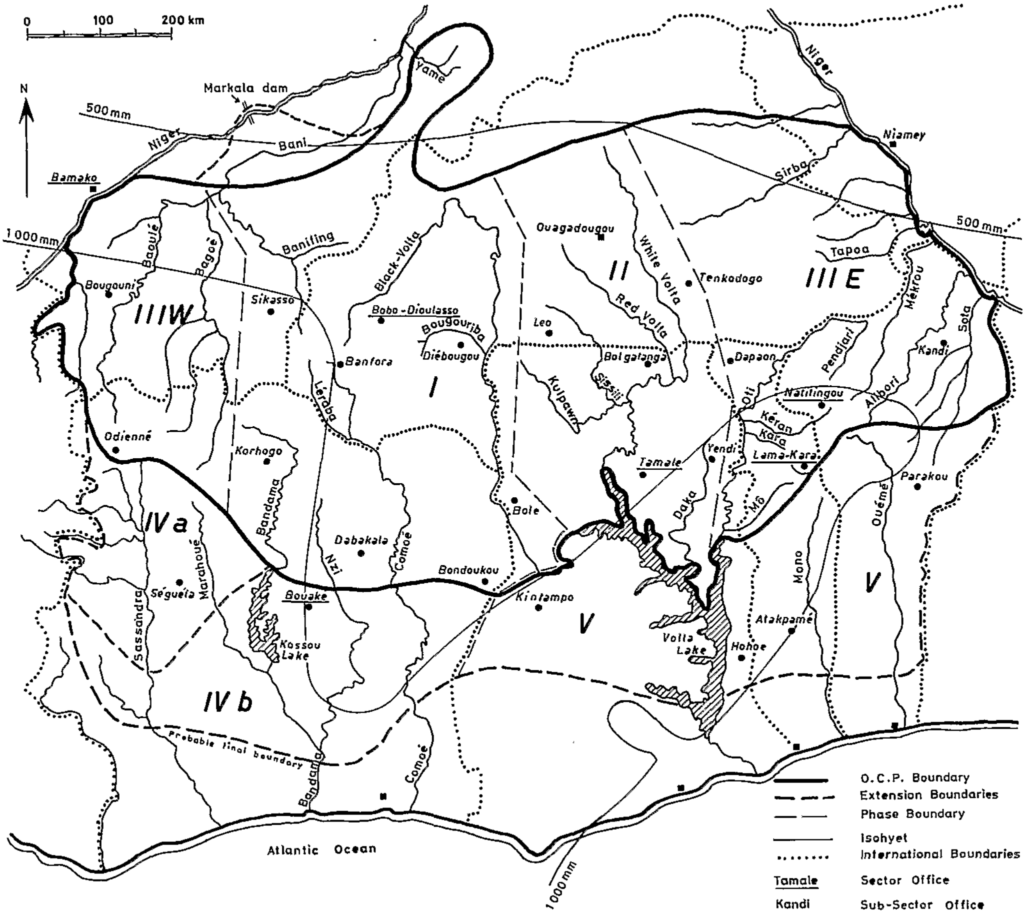

Fig. 2 The Onchocerciasis Control Programme Area, the main river systems and the location of the Sector and Sub-Sector offices. Operational phases are indicated by roman numerals

much modified by differences in relief and geology in the two halves of the area. Thus, most major rivers in the western half of the area are perennial, albeit having very reduced flow during the dry season. The eastern half of the area is much drier through the north-eastward flowing Pendjari and Sota rivers are perennial.

As pointed out by Crosskey (1956) the distribution of *S. damnosum* is probably governed by geology more than any other factor. This is clearly seen when consideration is given to the natural northern limit of distribution of *S. damnosum.* In the rocky Bandiagara area, *S. damnosum* extends north of 14°N whereas over most of the rest of the northern perimeter breeding is confined to areas south of 13°N. However, provision of a suitable breeding site such as the Markala Dam spillway (Fig. 2) results in a northern extension of breeding range. Thus, climate alone does not determine the northern limit of distribution.

The work of Dunbar (1966, 1969) and later Vajime and Dunbar (1975) and Quillévéré and Pendriez (1975) has shown that *S. damnosum* is a species complex of which the 6 species *S. damnosum s. str., S. sirbanum, S. squamosur, S. yahense, S. sanctipauli,* and *S. soubrense* are common in West Africa. Their distributions which differ substantially have been summarised by Vajime and Quillévéré (1978).

In much of the Programme area, large tracts of country are uninhabited. These zones correspond to the middle-belt of northern Nigeria where a variety of factors including animal and human trypanosomiasis, onchocerciasis, political upheavals, poorly adapted crops, soil exhaustion and inhospitable climates have been invoked to explain the phenomenon (Pullan 1964, Glover and Aitchison 1970). Where human populations are present, they are frequently unevenly distributed with crowding in upland areas and desertion of fertile and well watered valley bottoms. Much of this maldistribution of human populations is thought to be the result of the ravages of onchocerciasis (Hunter 1966, Waddy 1969, Rolland 1972, Bradley 1976).

Within the Programme area, it was estimated that over 1 million people were infected with onchocerciasis of whom at least 70,000 were blind or had serious impairment of sight.

Implementation of the Programme

In early 1974 the Programme headquarters was opened in Ouagadougou and a Vector Control Unit was established. The Unit has two basic tasks, planning and supervision of an aerial insecticidal operation aimed at destruction of the larvae and the evaluation of the pre- and post control situations from an entomological standpoint. The Unit has also been active in fostering research on the biology of the vector and its parasites and in supporting monitoring of the aquatic environment.

In order to carry out the Programme in the shortest possible time, implementation of control was scheduled to take place during the three-year period 1975–77 (Phases I–III). Subsequently the Programme has been given the responsibility of controlling additional areas of Ivory Coast (Phase IV) and of studying the feasibility and desirability of control in the southern parts of Ghana, Togo and Benin (Phase V) (Fig. 2). Details of the size of these areas and the estimated river lengths to be treated during wet season operations are given in Table 1.

Vector Control Operations

Choice of Insecticide

After careful consideration and field trials it was decided that an emulsifiable concentrate of Temephos (Abate®) formulated by Procida was efficient in eliminating *S. damnosum* larvae and was relatively innocuous to the non-target fauna, especially fish. In addition, it was of very low mammalian toxicity and had an excellent shelf life even in the harsh condi-

Table 1 Expansion of Programme Area

Zone	Surveillance started	Control started	Surface Area 1000 km²	Max. length of rivers treated km
Phase I	Aug. '74	Feb. '75	247	4500
Phase II	June '75	Mar. '76	134	2352
Phase III W	June '76	Mar. '77	77	3000
Phase III E	June '76	Mar. '77 – Jul. '77	196	4500
Original Area Total	–	–	654	14,352
Phase IV (Ivory Coast)	Mar. '77	Apr. '78 Mar. '79	110	3500
Extension Study Area (V)	June '78		111	4135
Totals	–	–	875	21,987

tions of tropical Africa. It has also been shown to be safe for use in drinking water (Laws et al. 1968).

Application of Insecticide

From the Tunis conference onward, it has been appreciated that without the use of aircraft. *S. damnosum* control on a large-scale is not feasible. Experience has shown that for the smaller more heavily wooded streams helicopters are essential for delivering the insecticide, and that for prospecting new areas and checking the efficacity of control activities such machines are invaluable. For control of larger more open rivers fixed-wing aeroplanes with their larger payloads have been chosen. To carry out this work it was considered that the employment of an experienced aerial contractor would be more satisfactory and economic than the purchase of aircraft and hiring pilots and engineers by WHO itself.

The equipment used has been Bell Jet Ranger 206B and Hughes 500C helicopters with Pilatus Porter PC6 fixed-wing aircraft.

Special treatment equipment has been developed, notably the "vide-vite" system, which allows rapid discharge of carefully measured quantities of insecticide (Parker 1975). A restrictor valve permits slow release where this is desired during dry season operations.

The rivers of the Programme area are treated with insecticide emulsion at rates of between 0.05 and 0.10 ppm, measured over a 10 minute period of flow.

The lower dosage rates are appropriate to fairly large fast flowing rivers during the wet season, the higher rates being used in small streams and during dry season conditions of intermittent flow in the larger rivers. Distance between dropping points varies greatly depending on the facies of each river. On large rivers during the wet season treatments made at 40 km intervals may suffice to eliminate all breeding of the vector, whereas in extreme dry season conditions each separate breeding site may require individual treatment.

In West Africa the temperature of the water in *S. damnosum* breeding sites normally varies between 22° and 32°C but may rise to 35°C. Development of the aquatic stage is very rapid. Only the larvae are killed by the insecticide and they may develop from egg to pupa in as little as 8 days, necessitating a weekly treatment cycle.

Treatment began in February 1975 using one Jet Ranger with a back-up machine available and have continued without interruption ever since. The present wet season fleet consists of 8 Hughes 500C helicopters and 2 Pilatus Porter PC6 fixed-wing aircraft. Table 2 gives an impression of the build-up of aerial operations. More details concerning control operations will be found in Walsh et al. (in the press)

Entomological Evaluation

The role of the Entomological Evaluation Network of the Vector Control Unit is to:

1. Provide pre-control data on *S. damnosum* densities, distribution and transmission potentials.
2. Evaluate the effect of the insecticidal treatments on the aquatic and adult stages of *Simulium damnosum.*
3. Evaluate the degree of transmission of *Onchocerca volvulus* that is taking place.
4. Provide up-to-date information on river levels so that discharge rates can be calculated by the Aerial Operations Officers and the correct doses of insecticides applied.

Organisation and Methods

The basic evaluation unit is the Catching Team made up of two vector collectors, one driver and an all-terrain vehicle.

Three or four catching teams are based at a Sub-Sector which consists of an office and a small laboratory in charge of an Entomological Technician. Three to five Sub-Sectors are grouped into a Sector each supervised by a graduate entomologist. Initially, there were seven sectors, two in Upper Volta and one in each of the other countries of the Programme area, excepting Niger. Subsequently, Ouagadougou, one of the Upper Volta Sectors was closed down.

Table 2 Build-up of Aerial Operations

	Hours flown			Insecticide dispensed (1000 litres)		
Year	Helicopter	F. Wing	Total	Helicopter	F. Wing	Total
1975	2683	541	3224	46	30	76
1976	4265	614	4879	80	50	130
1977	5358	1026	6384	84	71	155
1978	5356	1204	6560	95	121	216

The present situation is shown in Fig. 2. Within each Sector are located workshop facilities for repairing vehicles and an administrative office.

All Sub-Sectors and Sectors are linked with each other and with the Programme Headquarters at Ouagadougou by HF Radio-telephone operating on four channels.

Surveys for the Aquatic Stages of S. damnosum

Although the overall success of the control measures is estimated by the density of adult female *S. damnosum* attracted to human bait, the presence or absence of larvae and pupae in a river can give an immediate indication of the success of the previous treatment cycle. In addition, the discovery of immature stages in an untreated river usually forms the criterion for deciding whether a river should be included in the treatment schedule.

The majority of such surveys are carried out at the Sub-Sector level. Rivers are visited weekly or fortnightly at points accessible from the ground and known from experience to be difficult to treat or indicative of the condition of the river as a whole. Searches are normally timed to take place 24 or 48 hours after treatment, and are made by two persons. They continue for between 1/2 and 1 hour or until *S. damnosum* is found. The density of an infestation is recorded using a simple four-category system ranging from absent (0) to abundant (XXX) for each of the stages – eggs, young larvae, old larvae and pupae. The presence of other species of *Simulium* is also noted.

In addition, specimens are taken to the laboratory for microscopic examination and confirmation of the field identifications. Very light infestations, particularly when masked by other species such as *S. hargreavesi,* are usually found this way.

Details of each prospection are recorded on a special form, together with the date of the last treatment at each site where appropriate.

When the river is inaccessible from the ground, or when a large area needs to be surveyed rapidly the search is made by Senior Staff transported by helicopter using its faculty for landing on rocks and islands which cannot be reached from the bank.

Collections of Adult S. damnosum

Because the diurnal biting cycle varies with the season (Crosskey 1955, Le Berre 1966), catches of *S. damnosum* on human bait are standardised to cover an 11 hour day (0700 to 1800 h) at each catching site. This makes it possible to compare dry season densities, when the flies bite mainly in the morning and evening, with the wet season when peak biting may occur at midday. In practice, each of the two vector collectors in the team work alternate hours, giving 11 man/hours of catching per day. Densities are expressed as *S. damnosum* per man day.

The vector collector sits at a pre-determined place at each site, with his legs exposed below the knee. Flies coming to bite are caught singly in small plastic vials, and kept alive by packing in damp cotton in an insulated container. The total catch for each hour is recorded, together with notes on weather conditions.

At the end of each day the whole catch is usually sent to the Sub-Sector laboratory for dissection on the following day. If the catching point is very distant from the laboratory, the flies may not reach the laboratory until 48 hours after capture, however, they usually survive this period with little mortality.

(a) Choice of Points

Because their prime purpose is to routinely monitor the effect of the control measures capture points are where possible located at sites which experience has shown to favour the concentration of flies, and which are accessible from the ground for most of the year. Some are located near to villages selected for the epidemiological surveys to give an estimate of the transmission at those villages and the whole network of points is arranged to give a reasonable geographic coverage of the programme area.

Catches may be made for 1, 2 or 3 consecutive days per week depending on the current importance of that point to the assessment programme. For field research catches may be made every day using relays of catching teams.

At present, there are 258 principal catching stations in two categories; those which are visited at least once per week; and those which are visited at least once a fortnight. There are an additional 374 catching stations which are either visited very occasionally, or at very restricted periods of the year, or have been dropped in favour of adjacent better sites.

(b) Collection Circuits

At the beginning of each week the Sub-Sector and Sector Chiefs plan the collection programme for the current week. Normally the programme follows a regular routine, but sometimes modifications are required to give increased coverage of areas where biting densities are unsatisfactory or control may have broken down, or because of logistic problems such as vehicle breakdowns, or impassable roads. In this respect, the freedom of communication provided by the radio network is invaluable.

(c) Dissection and Recording of Catches

At the Sub-Sector laboratory, whenever possible, flies are dissected immediately on arrival.

Each fly is treated separately and, after being anaesthetised with chloroform it is placed in a drop of saline on a slide and examined under a dissecting microscope (magnification x 40). The abdomen is opened and the ovaries classified as parous or nulliparous using the technique of Lewis (1958). In cases where follicular relics are difficult to observe other criteria such as retained eggs, elasticity and size of ovaries, the presence of fat body, stage of Malpighian tubules and presence of meconium may be considered. Dissection details are recorded on a work sheet. If the fly is parous the dissection is continued by opening the head and thorax to determine whether it is harbouring *O. volvulus* type larvae. If nulliparous it is discarded.

Where the number of flies caught is large proportional samples from each hour of the day are dissected. When required infective larvae are preserved for parasitological studies (Omar and Schulz-Key 1978).

Since 1978, knowledge of the morphology of the adult females of the species within the *S. damnosum* complex has improved to such an extent that during special studies the flies can now be identified into species groups. For this, the colour of the basal wing tufts (Lewis and Duke 1966, Garms 1978) and the shape of the antennae (Quillévéré et al. 1977) have proved particularly useful as rapid methods.

Hydrological Data

Water levels are read by Sub-Sector staff as late in the week as possible, using the 132 gauges sited at strategic points on the treated rivers.

Where gauges coincide with capture points, or lie on their itinerary, this reading is done by vector collectors, otherwise the gauge site is incorporated in a prospection circuit. At a few points, special visits are made.

Treatment of Data

(a) Weekly Analysis

Each weekend, hydrological and entomological data, particularly regarding fly densities, parous rates and positive breeding surveys for *S. damnosum* are transmitted by radio to the Operations Bases at Bobo-Dioulasso and Tamale and the headquarters at Ouagadougou (Fig. 1). Maps are prepared showing the week's results and an immediate assessment of the control situation made. Plans for the following week's treatment are formulated each Monday morning and urgent prospections decided upon. Insecticide dosage rates are recalculated according to the most recent hydrological data.

(b) Monthly and Annual Analyses

At the end of each month the results of all catches and dissections are summarised by capture-point. The dissection work sheets are sorted and sent to Geneva for computer storage. All data on these sheets are recorded at the level of the individual fly. Thus, data are available for a considerable degree of analysis. So far analyses have been restricted to monthly and annual summaries, and the calculation of Annual Biting Rates (ABR) and Annual Transmission Potentials (ATP) (Walsh et al. 1978) but it is anticipated that as the volume of data increases greater use will be made of it.

For annual analyses, it has been found convenient to divide the year into three distinct climatic seasons. The cold dry season November to February; the hot dry season, March to May; and the wet season June to October. In the southern part of the programme the wet season usually begins at the beginning of April, but although some small rivers may begin to flow or show increased discharges, there is little general increase until late in May.

Criteria

Since it was never considered possible that *S. damnosum* could be eradicated from the Programme area, it was necessary at some stage to define a minimum level of infestation below which the objectives of the control measures could be considered to have been achieved.

In June 1977, a Scientific Working group met in Geneva to assess the Biomedical Criteria for Resettlement in the OCP area. After examining existing pre-control entomological and epidemiological data (some of which is given by Thylefors et al. 1978) it was concluded that the severity of eye lesions due to onchocerciasis in a population was related to the intensity of transmission as estimated by the ATP. The group also defined the concept of a "tolerable level of onchocerciasis infection" in a community as: "The attainment and maintenance, throughout the OCP area and among all persons living therein who were not already infected with *Onchocerca volvulus* at the outset of the campaign, of a zero incidence of the serious and irreversible ocular lesions resulting from onchocerciasis" (WHO 1977).

Furthermore, the available data suggested that people in villages situated in areas where the ATP, calculated on larvae in the head capsule, was less than 100 did not show irreversible eye lesions, and this level was accepted as a provisional maximum permissible level of transmission. An analysis of dissection data from flies caught biting near hyperendemic savanna villages showed that one infective 3rd stage larva indistinguishable from *O. volvulus* was normally found for every 10 flies dissected. Thus a second criterion of an ABR of less than 1000 was set for uninhabited areas where natural infections and ATPs were low or zero, but might rise to dangerous levels if resettled by persons already infected with onchocerciasis.

It was also recommended that calculations of ATPs and ABRs should, whenever possible, be based on at least four days' catches per month throughout the year.

Results

Surveys for Aquatic Stages

A summary of the total effort expended on surveys for aquatic stages of *S. damnosum* by each Sector during 1978 is given in Table 3. The number of visits made varied according to the seasonal nature and accessibility of the rivers. Thus in Ouagadougou Sector where all rivers cease flowing in the dry season only 483 visits were made, compared with Korhogo (3563) and Bamako (3985) where many rivers are perennial.

The proportion of positive sites also varied. The highest positive rates occurred in the Sectors of Tamale and Lama Kara, each of which contained a Sub-Sector in the uncontrolled extension study area (Phase V). When the data from these Sub-Sectors of Hohoe and Atakpame are deducted from the results of their sectors the positive rates fall to 5.4% and 3.7% respectively. The next highest rate of 9.9% in Natitingou Sector reflects the difficulties that have been experienced in treating the rivers of that Sector.

In every case, the percentage of positive sites tends to give a distorted picture of the rate of treatment success. This is the result of the non-random nature of the larval searches which are heavily concentrated at troublesome sites where experience has shown successful aerial treatments to be technically difficult.

Collections of Adult S. damnosum

The total effort expended on the collection and dissection of biting female *S. damnosum* is summarised in Table 4 for the four complete years of the Programme.

The increase in mean number of points visited per month and man-days worked between 1974–75 and 1976–77 reflects the expansion of the entomological evaluation network with the phases of the programme. The drop in man-days between 1976–77 and 1977–78 is due to the closure of the Sub-Sectors of Banfora and Leo and the reduction of evaluation in that area following the steady success (virtually 100%) of the control operations.

A total of almost 1.2 million *S. damnosum* had been collected in 52,040 man-days between November 1974 and October 1978. Of these, 56% were dissected to find 73.9% parous. The dissections revealed 32,200 infective

Table 3 Summary of *S. damnosum* breeding surveys 1978

Sector	No. of Visits made	No. +ve	% +ve
Bamako	3,985	202	5.1
Bobo-Dioulasso	1,690	59	3.5
Ouagadougou*	483	26	4.9
Korhogo	3,563	196	5.5
Tamale	1,611	211	13.1
Lama Kara	1,166	164	14.1
Natitingou	1,952	252	9.9
Total	14,450	1,110	7.7
Uncontrolled Sub-Sectors			
Hohoe	291	139	47.7
Atakpamc	181	127	70.2

*As originally defined. This Sector is now included in Tamale Sector.

Table 4 Summary of human bait catches for adult *S. damnosum*

Year Nov.– Oct.	Mean No. of points per month	Total Man/days worked	Total flies caught 1000s	Mean No. per day	Total dissected 1000s	% Parous	Total No. of Third Stage Larvae
1974–75	118	6,554	166.6	25.4	138.0	71.5	6,332
1975–76	193	12,343	211.8	17.2	157.7	76.3	6,923
1976–77	274	17,254	286.3	16.6	170.9	72.2	7,479
1977–78	274	15,889	532.6	33.5	207.7	75.4	11,466
Totals	–	52,040	1,197.3	23.0	674.3	73.9	32,200

3rd stage *O. volvulus* type larvae in head or thorax, giving an overall infection rate of 1 larva for every 20.9 flies.

The overall annual total catches show no dramatic fall in fly densities with the onset of insecticidal control because each year catches were made in uncontrolled areas as well. The higher catches of 1977–78 are the result of the extension of activities into the largely uncontrolled Phase IV area of the Ivory Coast, and the extension areas of the Volta regions of eastern Ghana and southern Togo where very high biting rates in excess of 200 per day are common.

Annual Biting Rates

Fig. 3 shows the ABR recorded for all 127 points at which sufficient pre-control data could be found. For Phase I this data was collected largely from OCCGE/ORSTOM records provided by the Director of the Institut de Récherche sur l'Onchocercose at Bouaké, Ivory Coast. Data for the other Phases was mostly collected by OCP teams while some data from the Red and White Voltas was obtained by J.D.M. Marr and C. Balay. The figure shows that at 90% of the points the ABR exceeded 4000 flies (11 per day) and in most of the Volta River basin itself exceeded 8000. The most notable areas of lower density were along the mid-sections of the Baoulé and Bagbé rivers of Mali and on the tributaries of the R. Niger in Niger. Only four points showed ABRs of less than the critical 1000, and three of these lay on the very seasonal rivers of Niger.

Biting rates recorded over the 1977–78 season (i.e. November 1977 to October 1978) at 144 representative points are shown in Fig. 4. At the 114 points located within the original programme area, biting fly populations have been drastically reduced, with 75% registering ABRs of below 4000. In the great majority of cases, the ABR is less than 500. However, there remains a substantial number of sites at which control has not resulted in acceptable levels, although the ABRs are usually much reduced from pre-control times. Some of these will be discussed in greater detail below. These sites nearly all lie in a band of about 200 km in width within the western, southern and eastern boundaries of the original programme area. In the south-west this situation has been the subject of intensive field research, and it is now concluded that since no local breeding could be found, the flies originate from outside the treated area and are probably transported by the humid SW monsoon winds (Garms et al. 1979). Most invading flies appear to belong to the two savanna species of the *S. damnosum* complex; *S. damnosum s. str.* and *S. sirbanum* though *S. squamosum* may also be implicated. Circumstantial evidence suggests that the same situation probably exists in the south-east and east.

An analysis of the mean daily biting rate of *S. damnosum* at some of the least successfully controlled points on the different systems is given in Table 5. Of these, points No. 1, 2, 7, 8, 9, 10 and 18 are considered to be influenced by invading flies since the highest numbers are taken during the "reinvasion season" between May and September. Points 8 and 9 show reduced densities in 1977–78 during

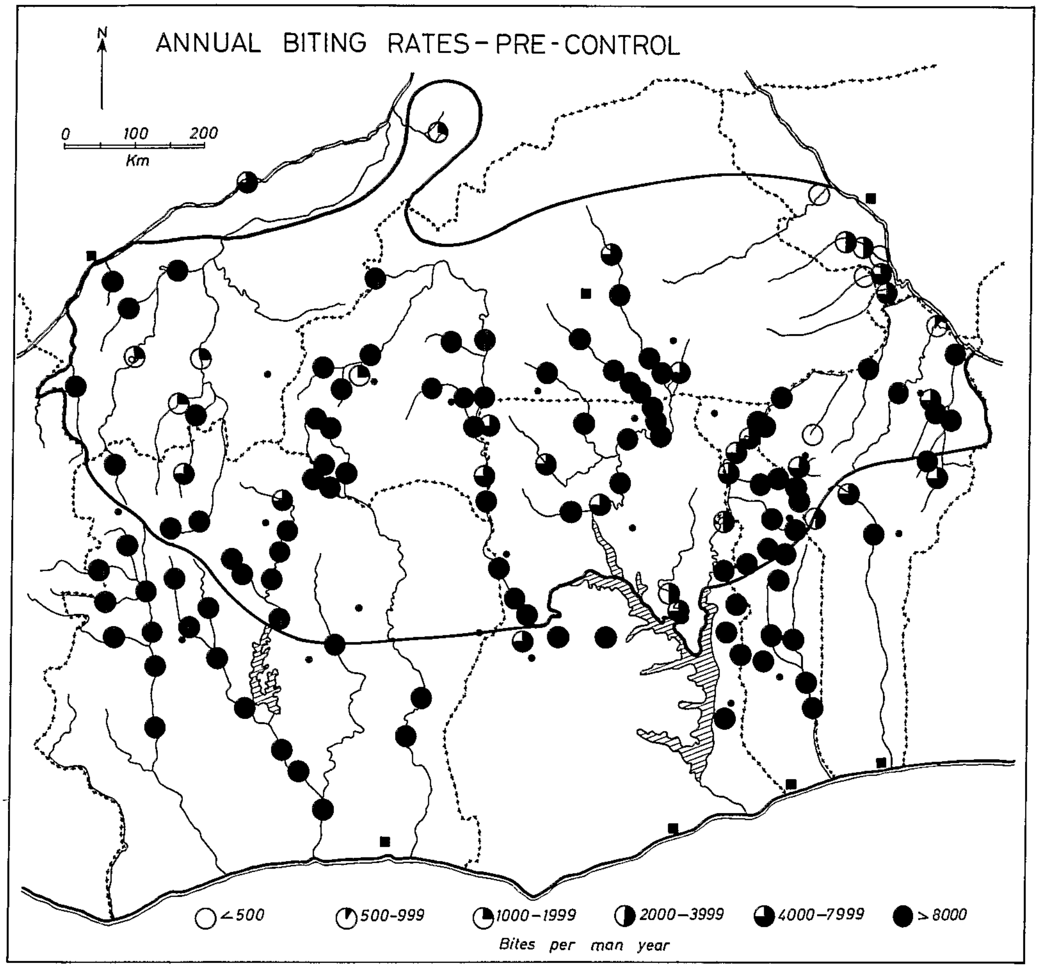

Fig. 3 Pre-control Annual Biting Rates from points at which sufficient data is available

this period when compared with previous years, and this is considered to reflect the effect of the expansion of larviciding into the Ivory Coast extension area in April 1978 (Table 1) on the rate of reinvasion.

The reasons for poor control at the other points are various. Points 5, 6, 12, 13, 14, 15, 16 and 17 have proved to be technically difficult to treat, either because of the configuration of the river or the presence of vegetation cover. The progressive improvement of the results indicates that modifications in techniques have reduced the extent of the residual breeding at these trouble spots. Kuoro Radier (3), is a special case where a breeding site on a nearby tributary of the R. Bagoé was not discovered until February 1978. Once this river was brought under control the situation improved.

Annual Transmission Potentials

Some pre-control data on Annual Transmission Potentials have been published in Davies et al. (1978) and more is given in Walsh et al. (in the press).

The ATPs for 1977–78 are shown in Fig. 5. Again ATPs above the acceptable level of 100

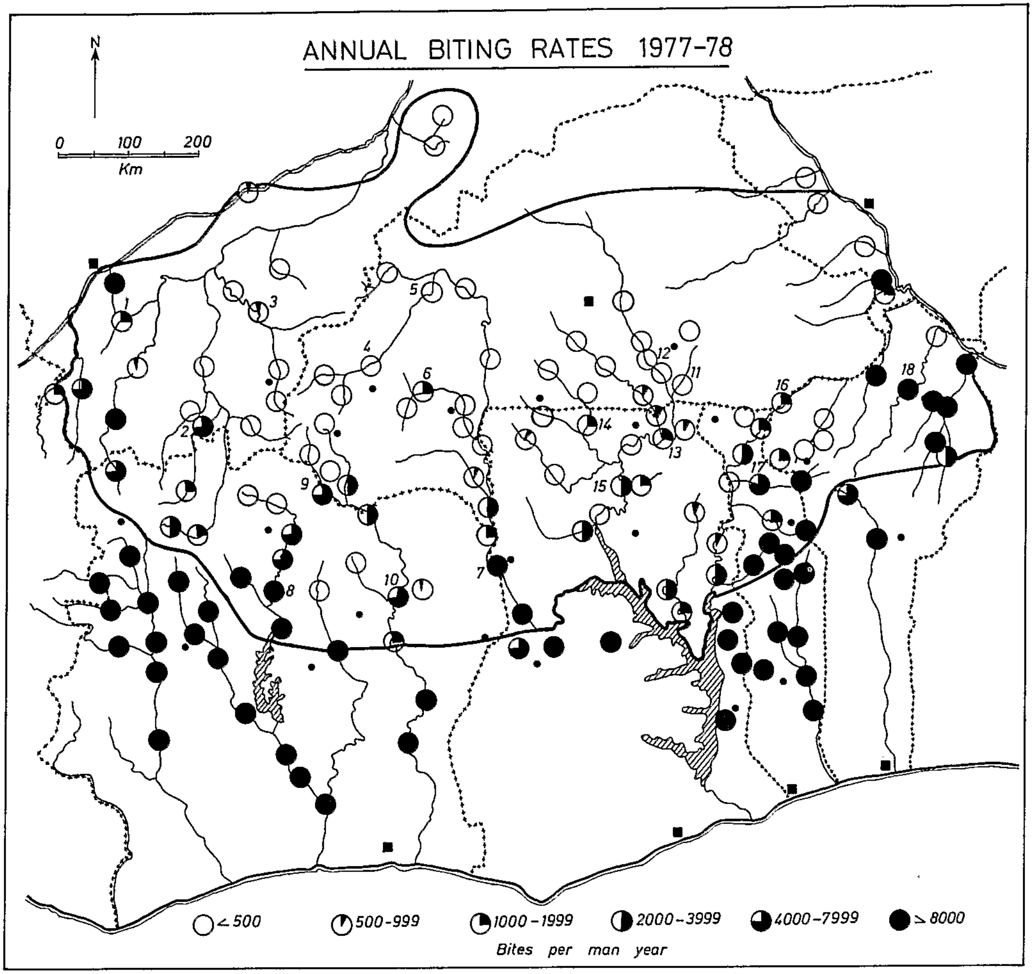

Fig. 4 Annual Biting Rates for the post-control period November 1977 to October 1978 for comparison with Fig. 3. Numbered sites refer to those listed in Table 5

are mostly found along the western, southern and eastern boundaries. Generally sites with ATPs above 100 coincide with sites where the ABR is over 1000. There are two obvious exceptions. The two points adjacent to Zongoiri Rapids (13) at the confluence of the White and Red Volta rivers where, although ABRs of less than 1000 were recorded, the ATPs exceeded 100. This is a densely populated hyperendemic area where the proportion of infected flies is very high. Over the whole year, an average of one 3rd stage larva is found in the head capsule for every 6.4. flies dissected, which is appreciably higher than the 1 in 10 average for most hyperendemic areas. The second concerns Naboulgou (17) where although an ABR of 4017 was recorded, the ATP was only 64. This point is situated in a game reserve where natural infections with *Onchocerca* larvae are low (one 3rd stage larva for every 45 flies dissected).

In the extension areas south of the programme less than a full year's data is available for the lower Bandama and Sassandra rivers. The catches that have been made show ABRs already in excess of 8000, but there is still insufficient data to calculate the ATPs.

Table 5 Mean Daily Catch of *S. damnosum* at the least successfully controlled points in each river system. Locations in Fig. 4 (Pre-control data from various sources underlined)

Site	Map No.	Pre OCP 1	Pre OCP 2	Pre OCP 3	74–75 1	74–75 2	74–75 3	75–76 1	75–76 2	75–76 3	76–77 1	76–77 2	76–77 3	77–78 1	77–78 2	77–78 3
Mpiéla	1									60	59	4	49	0	<1	12
Kankela	2	121		158						11	31	5	56	1	22	32
Kouoro Radier	3	34	49	132	57	3	21	4	14	13	37	1	15	<1	1	3
Lanviéra	4	118	233	138	51	1	4	1	14	1	2	<1	3	<1	1	2
Nwokuy	5				40	5	4	1	4	1	1	<1	1	<1	0	1
Nabéré	6	177	44	155	76	5	7	10	2	11	2	<1	4	3	5	5
Tagadi	7				235	15	359	41	6	91	10	1	33	26	28	177
Ch. Niaka.	8	50	52	46	96	43	113	10	8	22	8	6	42	38	33	9
Léraba Br.	9	147	105	240	164	49	86	8	51	76	3	9	40	16	28	15
Toupé	10		13	18	34	2	13	6	<1	2	2	0	15	7	4	14
Bagré	11						48	12	0	1	10	0	4	2	0	1
Zio-Zabré	12	71	13	277			80	19	<1	3	2	0	27	1	3	3
Zongoiri	13	34	29	54		33	66	41	3	10	6	<1	16	3	6	2
Nakong	14	2	18	71		0	20	8	0	4	1	0	13	1	3	9
Sugu	15	224	78					95	6	1	4	<1	5	20	1	1
Porga	16									30	57	<1	41	9	1	5
Naboulgou	17									79	200	1	35	25	0	2
Alibori	18									193	50	1	201	31	55	167

1 = Nov.-Feb. 2 = Mar.–May 3 = June–Oct.

Discussion

By the end of the last entomological assessment year in October 1978, the whole programme area had been under treatment for 15 months, although Phase I had been treated since February 1975, a period of 45 months. Thus, considerable experience and local knowledge had been built up amongst the staff and aerial contractors in Phases I and II, whilst knowledge of the terrain and local problems was still being acquired in Phase III W and in Phase III E.

One of the consequences of working in a tropical environment with single sharply defined wet and dry seasons is that difficulties arising from a particular association between the configuration of a breeding site and river discharge frequently have to wait until similar conditions recur the following year before they can be resolved. This sequence of events slows progress, and explains why many of the points shown in Table 5 were not successfully controlled until the second or third year of treatment.

It has already been shown that vector control in the central part of the OCP area has largely achieved its aims in that ABRs and ATPs have in most places fallen well below the defined maximum limits. In the peripheral areas, it is expected that the expansion of treatments into the extension areas to the south, such as Phase IV (Ivory Coast) which started in earnest in March, 1979, and Phase V (southern

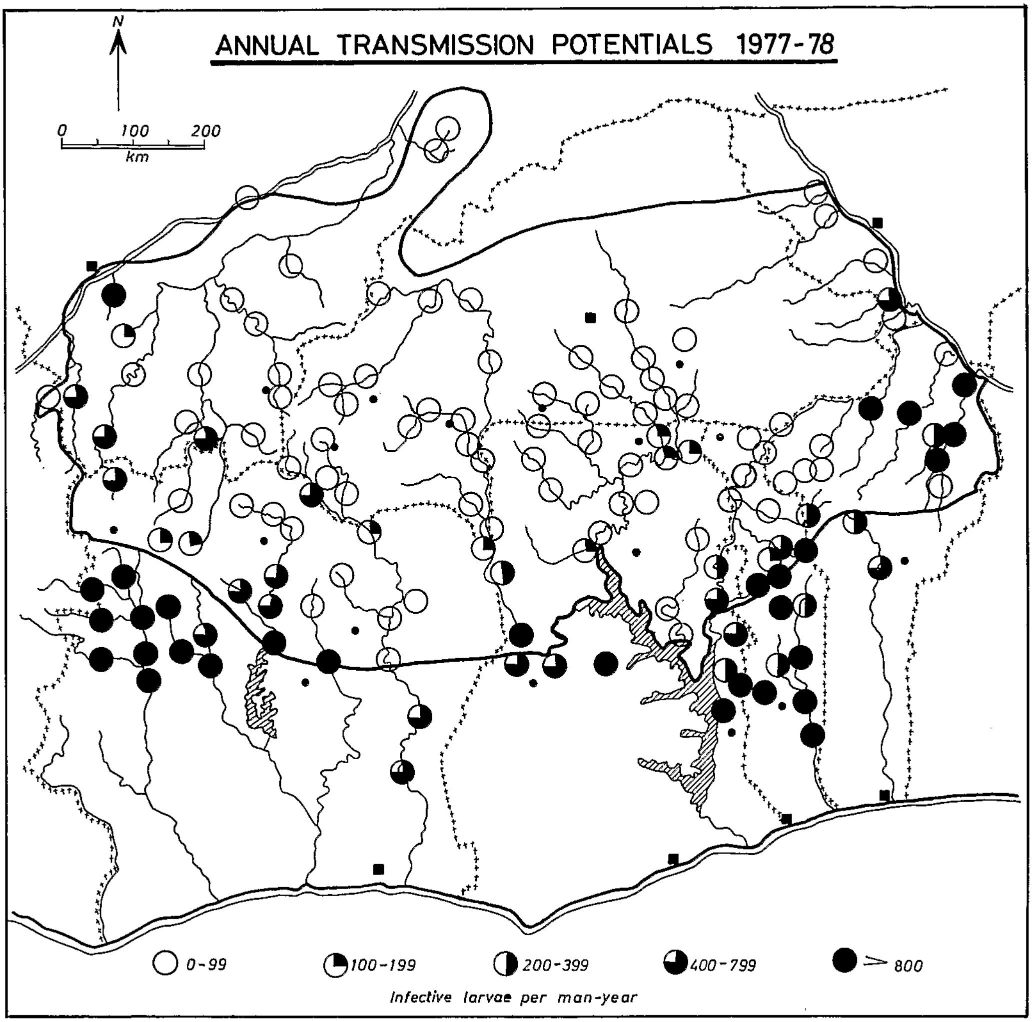

Fig. 5 Annual Transmission Potentials for the same sites within the Programme Area as given in Fig. 4. South of this area the data available is insufficient for the ATP to be calculated at all sites

areas of Ghana, Togo and Benin) which is at present being studied, will considerably reduce the numbers of invading *S. damnosum* thereby lowering biting densities over a larger area.

The attainment of these low biting densities, poses its own problem for the entomological evaluation of the programme. In the future it will be necessary to determine the minimum level of surveillance required to detect small pockets of reinfestation, and provide adequate data for calculating ATPs, while at the same time seeking to reduce costs. It is difficult to maintain the interest and efficiency of vector collectors when they consistently catch nothing, so that there is a great need for a trap which would approach the efficiency of human bait and could be left unattended for several days. Existing devices have been reviewed by Service (1977). So far nothing promising has been developed.

At low biting densities, the estimate of transmission as provided by the ATP may be subject to large fluctuations due to the rare occurrence of single flies carrying unusually high numbers of 3rd stage larvae. The epidemiological significance of such occasional heavily infected flies is not known, nor is it known whether short periods of high transmission, such as may result from temporary failures in treatment, are important as far as the prevalence of eye lesions is concerned. So, for the time being, the objective of the vector control activities must be to achieve the maximum possible reduction in the numbers of *S. damnosum.*

Within this rigorous target it has been possible, during the dry season, when *S. damnosum* densities have been practically zero to interrupt treatments of potentially productive breeding sites lying well inside the programme boundary. Evidence suggests that at this period, the initial population build-up is very slow, although the speed of development of the aquatic stages may be at its maximum. It may be that the few scattered egg batches and resultant low densities of larvae, are subject to intensive predation. In contrast, at the onset of the rainy season with markedly fluctuating water levels and rapid increase of potential breeding sites, the establishment of those species with great dispersal ability, high reproductive potential and fast development times is facilitated. In such conditions, simuliids are likely to be of considerable importance, arriving in large numbers, ovipositing in dense aggregations and swamping, at least temporarily, most biotic control agents. Thus populations in such conditions increase very rapidly. Nevertheless, even in the wet season, it has been possible to restrict larvicidal treatments to major breeding rivers in the heart of the Programme area and to cut back treatments on temporary streams in the late wet season before they cease to be suitable for *S. damnosum* breeding. However, owing to the great migratory ability of *S. damnosum* it has not so far been considered advisable to make the marked reductions originally evisaged in the PAG Report.

In the future, a comparison between the entomological and epidemiological findings of the Programme should provide the basis for a much better understanding of the likely medical consequences of a particular level of ATP experienced for a defined period. This increased knowledge together with the diminishing likelihood of a potential vector fly feeding from a parasitised man should enable the maximum permissible levels of ATP, and especially of ABR, to be gradually raised with a consequent reduction in the control effort required and in the cost of the Programme.

Acknowledgements

We wish to thank Dr. H. Agoua, Dr. C. Gboho, Mr. M. Ocran, Mr. J. Ouedraogo, Mr. A. Sékétéli, Dr. B. Simaga, Mr. A. Somé, Mr. S. Sowah, and Mr. G. Zerbo, entomologists, and the 25 entomological technicians who carried out the greater part of the activities described in this paper.

Former and present chiefs of aerial operations Messrs D.A.T. Baldry and B. Cliff and their supporting staff, Messrs. J. Henderickx, H. Orain, R. Lion, P. Pangalet, J. Basford and G. Fiasorgbor worked closely with the pilots and ground personnel of the two aerial contractors Evergreen Helicopters of USA, and Viking Helicopters of Canada, often under trying conditions, to ensure the smooth running of the control operation. They also assisted with the organisation of the collation of entomological data before its despatch to WHO Geneva where it was handled for computer processing by Mr. J. Dupuy and Mme. Losskey.

Valuable assistance in setting up the evaluation network was given by Messrs. W. Lawrence, J. Polin, and E. Turcotte, entomologists of the US Peace Corps.

We are grateful for the advice and assistance provided by Mr. J.D.M. Marr, Dr. B. Philippon, Dr. R. Garms, Dr. B.O.L. Duke and Dr. G. Quelennec.

None of this work could have been carried out without the diligence and cheerful enthusiasm of the evaluation staff, particularly the 258 vector collectors and 156 drivers together with the motor workshop staff.

Finally we wish to acknowledge the encouragement of Dr. P. Ziegler and Mr. M.Ls. Bazin separately directors of the Programme, and the support provided by Mr. R. Helmholz and his administrative team.

Literature

Aubreville, A., P. Duvigneaud, A.C. Hoyle, R.J.W. Keay, F.A. Mendonça, R.E.G. Pichi-Sermolli: Vegetation map of Africa south of the Tropic of Cancer. UNESCO (1958) Oxford Univ. Press.

Blacklock, D.B.: The development of *Onchocerca volvulus* in *Simulium damnosum.* Ann. Trop. Med. Parasit. 20 (1926a) 1–48

Blacklock, D.B.: The further development of *Onchocerca volvulus* Leuckart in *Simulium damnosum* Theobald. Ann. Trop. Med. Parasit. 20 (1926b) 203–218

Bradley, A.K.: Effects of onchocerciasis on settlement in the middle Hawal Valley, Nigeria. Trans. Roy. Soc. Trop. Med. Hyg. 70 (1976)

Crosskey, R.W.: Infection of *Simulium damnosum* with *Onchocerca volvulus* during the wet season in Northern Nigeria. Ann. Trop. Med. Parasit. 48 (1954) 152–159

Crosskey, R.W.: Observations on the bionomics of adult *Simulium damnosum* Theobald (Diptera: Simuliidae) in Northern Nigeria. Ann. Trop. Med. Parasit. 49 (1955) 142–153

Crosskey, R.W.: The distribution of *Simulium damnosum* Theobald in Northern Nigeria. Trans. Roy. Soc. Trop. Med. Hyg. 50 (1956) 379–392

Davies, J.B.: The *Simulium* control scheme at Abuja, Northern Nigeria, and its effect on the prevalence of onchocerciasis in the area. Bull. Wld. Hlth. Org. 39 (1968) 187–207

Davies, J.B., R.W. Crosskey, M.R.L. Johnston, M.E. Crosskey: The control of *Simulium damnosum* at Abuja, Northern Nigeria 1955–60. Bull. Wld. Hlth. Org. 27 (1962) 491–510

Davies, J.B., R. Le Berre, J.F. Walsh, B. Cliff: Onchocerciasis and *Simulium* control in the Volta River Basin. Mosq. News 38 (1978) 466–472

Dunbar, R.W.: Four sibling species included in *Simulium damnosum* Theobald (Diptera: Simuliidae) from Uganda. Nature (Lond.) 209 (1966) 597–599

Dunbar, R.W.: Nine cytological segregates in the *Simulium damnosum* complex. Bull. Wld. Hlth. Org. 40 (1969) 974–979

Fairchild, G.B., E.A. Barreda: DDT as a larvicide against *Simulium.* J. econ. Ent. 38 (1945) 694–699

Garms, R.: Use of morphological characters in the study of *Simulium damnosum* s.l. populations in West Africa. Tropenmed. Parasit. 29 (1978) 483–491

Garms, R., J.F. Walsh, J.B. Davies: Studies on the reinvasion of the Onchocerciasis Control Programme in the Volta River Basin by *Simulium damnosum* s.l. with emphasis on the South-western areas. Tropenmed. Parasit. 30 (1979) 345–362

Glover, P.E., P.J. Aitchison: Some causes of depopulation in Northern Nigeria. Nigerian Field 35 (1970) 12–28

Hitchen, C.S., H.H. Goiny: Note on the control of *Simulium damnosum* in the region of the Kainji Dam Project, Northern Nigeria. WHO Geneva (1966) WHO/Oncho/66.43, mimeographed, 5p

Hunter, J.M.: River Blindness in Nangodi, northern Ghana: a hypothesis of cyclical advance and retreat. Geogr. Rev. 56 (1966) 398–416

Laws, E.R., V.A. Sedlack, J.W. Miles, C.R. Joseph, J.R. Lacomba, A.D. Rivera: Field study of the safety of Abate for treating potable water and observations on the effectiveness of a control programme involving both Abate and Malathion. Bull. Wld. Hlth. Org. 38 (1968) 439–445

Le Berre, R.: Contribution à l'étude biologique et écologique de *Simulium damnosum* Theobald 1903 (Diptera: Simuliidae). Mémoirs ORSTOM 17 (1966) 204 p

Le Berre, R.: Bilan sommaire pour 1967 de lutte contre le vecteur de l'Onchocercose. Méd. Afr. Noire 15 (1968) 71–2

Le Berre, R., M. Ovazza, E. Juge: Resultats d'une campagne larvicide contre *Simulium damnosum* Theobald (Diptera: Simuliidae) en Afrique de l'ouest. Proc. XII Cong. Ent. London 1964 (1965) Section 12, 811

Lewis, D.J.: Aspects of the structure, biology and study of *Simulium damnosum.* Ann. Trop. Med. Parasit. 51 (1957) 340–358

Lewis, D.J.: Observations on *Simulium damnosum* at Lokoja in Northern Nigeria. Ann. Trop. Med. Parasit. 52 (1958) 216–231

Lewis, D.J.: Observations on *Simulium damnosum* in the Southern Cameroons and Liberia. Ann. trop. Med Parasit. 54 (1960) 208–223

Lewis, D.J., B.O.L. Duke: Onchocerca–Simulium complexes. II. Variation in West African female *Simulium damnosum.* Ann. Trop. Med. Parasit. 60 (1966) 337–346

McMahon, J.P., R.B. Highton, H. Goiny: The eradication of *Simulium neavei* from Kenya. Bull. Wld. Hlth. Org. 19 (1958) 75–107

Neilson, M.S.: Introduction to the flowering plants of West Africa. Univ. of London Press. (1965) 264 pp.

Omar, M.S., H. Schulz-Key: Acid phosphatase activity in the larval stages of *Onchocerca volvulus* developing in the vector *Simulium damnosum.* Tropenmed. Parasit. 29 (1978) 359–363

Ovazza, M., J. Coz, L. Ovazza: Etude des populations de *Simulium damnosum* Theobald, 1903 (Diptera Simuliidae) en zones de gites non-permanents. I. Observations sur les variations de quelques-uns de caracteres utilises dans l'estimation de l'age physiologique. Bull. Soc. Path. exot. 58 (1965a) 938–950

Ovazza, M., L. Ovazza, G. Balay: Etude des populations de *Simulium damnosum* Theobald, 1903 (Diptera: Simuliidae) en zones de gites non-permanents. II. Variations saisonnaires se produisant dans les populations adultes et preimaginales. Discussion des differents hypotheses que peuvent expliquer le maintien de l'éspace dans les régions sèches. Bull. Soc. Path. exot. 58 (1965b) 1118–1154

Parker, J.D.: The use of aircraft in the WHO Onchocerciasis Control Programme. Proc. V. Agricultural Aviation Congress, Warwickshire, England 22–25 Sept. 1975, 127–136

Prost, A.: Situation dans un foyer d'Onchocercose du Mali après treize ans de controle anti-Simulidien. 1. Aspects parasitologiques. Ann. Soc. belge Méd. trop. 57 (1977) 569–575

Pullan, R.A.: The concept of the middle belt in Nigeria – an attempt at a climatic definition. Nigerian. geog. J. 5 (1964) 39–52

Quillévéré, D., B. Pendriez: Etude du complex *Simulium damnosum* en Afrique de l'Quest II. Répartition géographique des cytotypes en Cote d'Ivoire. Cah. ORSTOM. Sér. Ent. méd. Parasit. 13 (1975) 165–172

Quillévéré, D., Y. Sechan, B. Pendriez: Etude du complex *Simulium damnosum* en Afrique de l'Quest V. Identification morphologique des femelles en Cote d'Ivoire. Tropenmed. Parasit. 28 (1977) 244–253

Rolland, A.: Onchocerciasis in the village of Saint Pierre: an unhappy experience of repopulation in an uncontrolled endemic area. Trans. R. Soc. Trop. Med. Hyg. 66 (1972) 913–915

Service, M.W.: Methods for sampling adult Simuliidae, with special reference to the *Simulium damnosum* complex. Tropical Pest Bulletin 5 (1977) 48 pp.

Taufflieb, R.: Une campagne de lutte contre *Simulium damnosum* au Mayo Kebbi. Bull. Soc. Path. exot. 48 (1955) 564–576

Thylefors, B., B. Philippon, A. Prost: Transmission potentials of *Onchocerca volvulus* and the associated intensity of onchocerciasis in a Sudan savanna area. Tropenmed. Parasit. 29 (1978) 346–354

Thylefors, B., A. Rolland: Situation dans un foyer d'Onchocercose du Mali après treize ans de controle anti-Simulidien. 2. Aspects oculaires. Ann. Soc. belge Méd. trop. 57 (1977) 577–582

Vajime, C.G., R.W. Dunbar: Chromosomal identifications of eight species of the sub-genus *Edwardsellum* near and including *Simulium (Edwardsellum) damnosum* Theobald (Diptera: Simuliidae) Tropenmed. Parasit. 26 (1975) 111–138

Vajime, C.G., D. Quillévéré: The distribution of the *Simulium damnosum* complex in West Africa with particular reference to the Onchocerciasis Control Programme Area. Tropenmed. Parasit. 29 (1978) 473–482

Waddy, B.B.: Prospects for the control of onchocerciasis in Africa. With special reference to the Volta River Basin. Bull. Wld. Hlth. Org. 40 (1969) 843–858

Walsh, J.F.: The control of *Simulium damnosum* in the River Niger and its tributaries in relation to the Kainji Lake research project, covering the period 1961 to 1969. WHO unpublished mimeographed document PD 70.4 (1970) 33 p + 12 figs.

Walsh, J.F., J.B. Davies, B. Cliff: The World Health Organisation Onchocerciasis Control Programme in the Volta River Basin. In: "Blackflies: The future for biological methods in integrated control". Ed. M. Laird (in the press).

Walsh, J.F., J.B. Davies, R. Le Berre, R. Garms: Standardization of criteria for assessing the effect of *Simulium* control in onchocerciasis control programmes. Trans. R. Soc. Trop. Med. Hyg. 72 (1978) 675–676

Wanson, M., L. Courtois, B. Lebied: L'éradication du *Simulium damnosum* (Theobald) à Léopoldville. Ann. soc. belge. Méd. trop. 29 (1949) 373–403

WHO: The biomedical criteria for resettlement in the Volta Basin Onchocerciasis Control Programme Area (OCP). Report of a Scientific Advisory Panel Working Group. WHO. Mimeograph OCP/SAP/77.1 (1977) 13 pp.

Mr. J.F. Walsh, Dr. J.B. Davies, World Health Organization, Onchocerciasis Control Programme, B.P. 549, Ouagadougou, Upper Volta, West Africa
Dr. R. Le Berre, World Health Organization, CH-1211 Geneva 27, Switzerland

30. Jahrgang Heft 3 September 1979 Seite 265–408

Sonderdruck

Tropenmedizin und Parasitologie

Organ der Deutschen Tropenmedizinischen Gesellschaft

Tropenmed. Parasit. 30 (1979) 328–344

Entomological Aspects of the First Five Years of the Onchocerciasis Control Programme in the Volta River Basin

J.F. Walsh, J.B. Davies, R. Le Berre

World Health Organization, Onchocerciasis Control Programme, Ouagadougou, Haute Volta, West Africa (Programme Director: Mr Marc Ls. Bazin)