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A Survey of *Simulium* Control in Africa

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It has become possible to control or even eradicate the Simulium *fly vectors of* Onchocerca volvulus, *the causative organism of onchocerciasis. There are two vectors in Africa—namely,* S. damnosum, *characteristic of the rivers of West Africa, and* S. neavei, *which breeds on the carapaces of crabs in the streams of East Africa. The use of DDT applied to the water at a concentration as low as 0.1 p.p.m. for 30 minutes eliminates the larvae of* Simulium. *Such larvicidal methods have eradicated* S. neavei *from western Kenya and virtually eradicated* S. damnosum *from the Victoria Nile in Uganda. Excellent control sufficient to render the transmission of onchocerciasis almost negligible has been obtained at Léopoldville (Republic of the Congo) and in circumscribed areas in southern Chad, Northern Nigeria, and Sierra Leone. The following survey describes operational research on* Simulium *control carried out in Kenya, Uganda, the Congo, Chad, Nigeria, Ghana, Upper Volta and Sierra Leone.*

The insect vectors of *Onchocerca volvulus*, the filarian parasite that causes onchocerciasis in humans, are the black-flies *Simulium damnosum* and *S. neavei*. The aquatic larvae of these insects, which breed in rivers and streams, are susceptible to elimination by DDT and other insecticides. Complete eradication without reinfestation has thus been achieved with *S. neavei* in western Kenya and *S. damnosum* in central Uganda, while effective but necessarily continuing control operations have been maintained against *S. damnosum* at Léopoldville (Republic of the Congo), in central Nigeria, and in up-country Sierra Leone, and against *S. neavei* in western Uganda. Evaluation of these and other operations, for possible wider application, was the object of a study tour undertaken by the author in mid-1960 as a WHO consultant.

CONTROL OR ERADICATION OF *SIMULIUM NEAVEI*

ERADICATION OPERATIONS IN KENYA

The presence of *S. neavei* in Kenya was restricted to the region around the Kavirondo Gulf of Lake Victoria Nyanza, at altitudes of 4000-6000 feet[2] (Fig. 1). Its larvae developed on the carapace of the freshwater crab *Potamonautes niloticus*, which is found in the sunny cascades of the rivers where the banks are wooded. The adult flies were found in valleys with high-canopy forest, usually upstream of the larval breeding-places—sometimes as much as 15 miles[3] upstream. *S. neavei* was the only species in the region to bite man, and in onchocerciasis areas as many as 10% of the flies carried *O. volvulus*. Two closely related species, *S. nyasalandicum* and *S. woodi*, whose larvae develop commensally on crabs, are more widespread but their adult stages do not bite man. *S. woodi* is found in the exhalant passage of the branchial chamber of *P. niloticus*, and spins an unusually coarse cocoon (McMahon, 1957a). *S. nyasalandicum* is found on *P. niloticus* even in the open country below 4000 feet and even above the point where this crab is succeeded by *P. granviki* in cooler waters.

The species *S. neavei* has now been eradicated from Kenya by DDT applied to the rivers as a larvicide. First, an isolated focus of 65 square miles[4] in the Kodera region, where a 70% prevalence of oncho-

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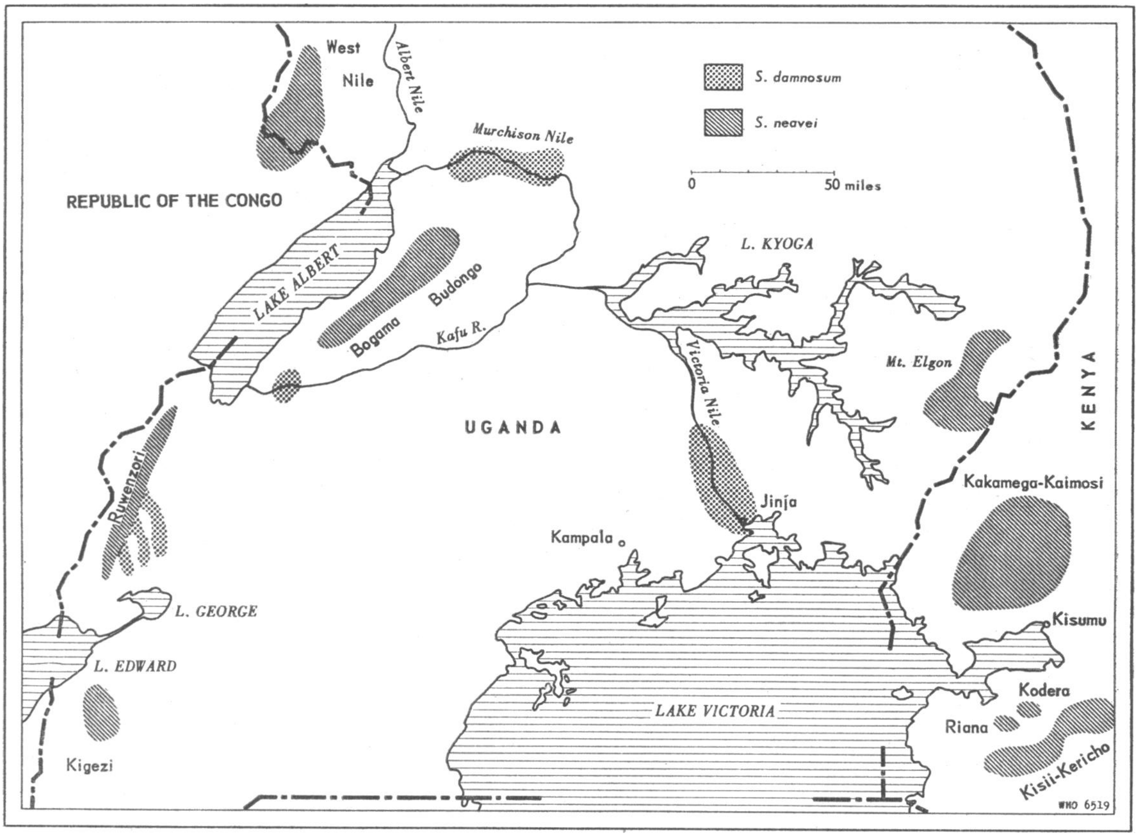
[2] 1 foot = 0.3 m.

[3] 1 mile = 1.6 km.

[4] 1 square mile = 2.6 km².

FIG. 1
DISTRIBUTION OF *SIMULIUM NEAVEI* AND *S. DAMNOSUM* IN EAST AFRICA



cerciasis caused it to be called the " Valley of the Blind ", was treated in 1946 with 13 applications of DDT at 2-5 p.p.m./30 min. between January and June (Garnham & McMahon, 1947). The adults disappeared by March and have never reappeared (Garnham & McMahon, 1954); the prevalence of onchocerciasis in children subsequently born in Kodera became nil (Grounds, 1958; Nelson & Grounds, 1958). Artificial deforestation of a neighbouring focus of 16 sq. miles on the lower Riana river, performed in 1943, achieved spot eradication of *S. neavei* by 1947.

A circumscribed area of infestation in the Kakamega-Kaimosi districts, to the extent of 1500 sq. miles, was treated in 1947-48 with 11 applications of DDT at 1-2.5 p.p.m./30 min. between November and April (McMahon, Highton & Goiny, 1957). *S. neavei* reappeared in the northern half in the following year. It became clear that the treated area, delineated by the presence of adult flies, had not included all the rivers in which larvae developed, and should have included the Nzoia river to the north.

Two large contiguous areas of infestation south of Kodera—namely, the Kisii and Kericho areas totalling together 1150 sq. miles—were treated in 1952-53 with 10 applications of DDT at 0.5-1 p.p.m./30 min. between October and January. By this time the larvae had been discovered to breed on the crab *P. niloticus* (van Someren & McMahon, 1950; McMahon, 1951, 1952) and so the area to be treated was correctly delineated. As a result the treatment was followed by the complete disappearance of *S. neavei* from the areas.

The Kakamega-Kaimosi sector was again treated in 1954; the area of application was enlarged to 2000 sq. miles to include the Nzoia river, which was found to be sufficiently isolated from reinfestation from Mount Elgon across the Uganda border. The area was treated with 7 applications of DDT at 0.5-2 p.p.m./30 min. between September and December. *S. neavei* disappeared, but in 1955 a pocket reappeared on the eastern boundary, on the upper Yala river. This was re-treated in February-May 1956, and no *S. neavei* have been found since. Thus J. P. McMahon and his colleagues R. B. Highton and H. H. Goiny could justly claim in 1958 to have eradicated *S. neavei* from Kenya.

CONTROL OPERATIONS IN UGANDA

In eastern Uganda, *S. neavei* occurs in a large crescent around the western side of Mount Elgon. In western Uganda it is present in Kigezi Province, in the foothills of the Ruwenzori Mountains, along the escarpment on the east side of Lake Albert, and in the western highlands of West Nile Province (Fig. 1). It is absent from the large central region of the Protectorate, which is mainly a vast plain. *S. neavei* is the only species found on the integument of crabs, *S. nyasalandicum* not having been found in Uganda. The crab host is *P. niloticus* in the lower reaches, but higher upstream it is *P. johnstonei* on the Albert escarpment and a species close to *P. beradi* on Mount Elgon. Although onchocerciasis is prevalent in these regions, blindness is comparatively rare, joint pains and "hanging-groin" being the principal symptoms.

The Mount Elgon area was treated in 1957 with 12 applications of DDT at 0.5 p.p.m./30 min. at fortnightly intervals between January and April (Barnley & Prentice, 1958). Arkotine 18 (an 18% emulsifiable concentrate) was used for the larger streams (up to 70 cusecs [1]). Smaller streams (less than 5 cusecs) were treated with a token dose of 1 litre of Arkotine 18, or with bags of vermiculite on which this concentrate had been adsorbed. Although the operation was performed in the dry season, in that year the streams continually increased in volume during the period. Mount Elgon is an area of very heavy rainfall, particularly in the south-western sector where Mount Nkokonjeru projects into the plain. On either side of this ridge the river systems, particularly the Namatala and Manafwa, are exceedingly complex. The plantations of banana and coffee, and copious ornamental trees, provide perfect passage for *S. neavei* to fly up into the high-canopy forest, which starts at 5500 feet. The human population is large, and the prevalence of onchocerciasis from 80% to 90%; the parasite rate in the flies was as high as 25%. The terrain is precipitous, and the footing either slippery clay or choked with brush.

The operation thus proved not only more difficult, but also much more extensive, than expected. In the Bulucheke area alone (containing the Manafwa river) 158 dosing-points were found to be necessary. Along the Namatala, the topography was so complex that headwaters of breeding-places were easily confused one with another. Once the cycles of treatment had been embarked on, it was impossible to spot every stream which appeared with the increasing rains. And so the operation never reduced the adult-fly count to zero, and the numbers recovered their normal level within a year.

Much greater success was eventually obtained with the Budongo Forest, located towards the east end of the Lake Albert escarpment (Barnley & Prentice, 1958). Here the prevalence of onchocerciasis was about 80% among the local population and immigrant labour from the West Nile district employed on logging and sawmill operations; the parasite-rate in the *S. neavei* flies was 20%. The Budongo-Siba area, totalling 160 sq. miles, was treated in 1955-56 with DDT at 0.5 p.p.m./30 min. in 12 successive applications at 10-day intervals. There was a total of 20 dosing-points on 5 streams through the forest, and Arkotine emulsifiable concentrate was applied from constant-flow machines. The first series of treatments decisively reduced the number of flies, but repopulation developed within 6 months.

Treatments were therefore resumed, being carried out at fortnightly intervals by the Budongo Sawmills Company, using kerosene cans with nail-holes for the larger streams, and a 3-minute pour for the smaller streams. This resulted in the disappearance of the fly by the end of 1957. Treatments were continued at intervals of 3 weeks, progressively increasing to intervals of 6 weeks. The fly has not reappeared, treatments being continued at 6-week intervals at a cost of 1200 EA shillings [2] per year for insecticide.

[1] 1 cusec = 1 cubic foot per second (1 cu.ft = 0.628 m³ —see footnote *a* in Table 2).

[2] 7.14 East African shillings = US$1.00.

OPERATIONS AND STUDIES IN NEIGHBOURING COUNTRIES

East and south-east of Nyanza province of Kenya, *S. neavei* is absent; however, it reappears in the Usumbara mountains of north-eastern Tanganyika, where Lewis (1960) found two species of the *neavei* group breeding on the crab *P. lirrangensis* at Amani. East of Uganda, *S. neavei* is responsible for onchocerciasis in the Congo basin, notably in the area between Stanleyville and the Lomani river, where the larvae breed on *P. lirrangensis*, *P. stanleyensis*, *P. ballayi*, *P. langi* and (most particularly) on an unidentified species of crab. Further south-west there is another focus of *S. neavei* and onchocerciasis in the basin of the Sankuru river (Lebrun, 1954). In the western Congo a form of *S. neavei* has been described as *S. renauxi*, and is a vector of onchocerciasis in the Inzia district. Further north-west, a species of the *neavei* group was found on crabs in streams at less than 1000 feet altitude between Brazzaville and Gabon (Ovazza, 1957). The same species, described as *S. ovazzae*, was found on the carapaces of *Potamon chaperi* on the river Noun in the west of Cameroun (Grenier & Mouchet, 1959).

Control of *S. neavei* was undertaken around Bojuma, 60 miles west of Stanleyville, against larvae breeding in streams emptying into the Congo river (Browne, 1960), A series of 10 applications were made at 10-day intervals with DDT at 2 p.p.m./30 min. A 25% emulsion concentrate was employed (Geigy's Neocid M25). This treatment resulted in almost complete disappearance of the adult fly, but the area, very approximately 1000 sq. miles, became entirely repopulated 6 months later.

ELEMENTS OF A SUCCESSFUL ERADICATION OPERATION

The eradication of *S. neavei* from Kenya was rendered possible by the isolation of the infested areas, and was achieved by a system of attack which, because it ultimately proved successful, can serve as an example for subsequent attempts at eradication of *S. neavei*. There are two main elements in the success of the Kenya workers. Firstly, from reconnaissance they were able to subdivide the infested area into individual foci separated by a 20-mile fly-free zone preventing reinvasion, where even the largest focus could be covered by 5 teams in each application cycle of 14 days. Secondly, they were so systematic in their routine and records that they could immediately detect points of control failure and make the right decision; the first failure in the Kakamega-Kaimosi area in 1948 was irremediable, and so the attack was disengaged and then resumed 4 years later with the delimitation of the area corrected to include the Nzoia river. The new attack also met with a control failure on the upper Yala, but this was detected quickly and could be remedied, thus achieving final success in eradication.

The fundamental element of the system of the Kenya workers was a sense of topography. Each operation was preceded by the examination on foot of every river and tributary stream in the area. At the same time the prevalence of adult *S. neavei* was assessed by counts on exposed humans, taking particular pains to determine precisely the outer limits of adult distribution. The rivers were similarly examined by crab catches to determine the limits of *P. niloticus* and *S. neavei* larvae. The results were entered currently in a master book in which the facing page bore a detailed map of the relevant section of the river system. This mapping subsequently became invaluable when the actual application was made, which was only after the area had been scrutinized in detail, times and capabilities gauged, roads and trails made or improved, and discharge rates of all but the smallest streams assessed.

Rivers were treated upstream from the infestation, at a point where *P. niloticus* had been replaced by *P. granviki*, or where larval identification had shown *S. neavei* to be replaced by *S. nyasalandicum*. On the day of treatment it was necessary also to dose the upper tributaries to prevent the escape of crabs into them; the upper section of the main river was also treated to provide a "backstop" against crabs escaping upstream from the main treatment. A checking team followed the passage of the insecticide downstream by observing the disappearance of susceptible aquatic insects used as indicators. Lower tributaries were treated on the following day. This checking immediately indicated where additional treatments were needed elsewhere on the river; for example, although the Yala and Nzoia (high-volume, "good-carrying" rivers) needed only one application for their respective 30-mile and 60-mile lengths, yet the Juja (a shallow stony river which evidently filtered or "rubbed out" the DDT) required 5 treating-points at 10-mile intervals, while the Sisi (a sluggish stream with stagnant stretches interspersed with the occasional cascade) required treating at 15 points.

The operation was so systematic and thorough that questions of formulation of the insecticide became secondary and there was no need for complicated dispensing equipment. Initially an oil emulsion was used; it failed in one highly turbid river (apparently owing to the breaking of the emulsion), but the failure was immediately spotted by the checking team, which redosed it and remedied the situation. In the final operation (Kakamega-Kaimosi) a miscible oil was used containing 18% DDT (Shell Arkotine SD 18 emulsifiable concentrate). Enough DDT for the treatment was put in a 4-gallon [1] kerosene can and water was added to volume. It was transferred to a similar can used for application, which delivers its full contents in 30 minutes if 3 holes (each $^3/_{16}$ inch [2] in diameter) have been punched in it with a 4-inch nail.

The operation was studded with safeguards against underdosing. Initial operations were at very high doses of DDT, which were finally reduced to 0.5 p.p.m. for large rivers (e.g., the Yala at 700 cusecs), and to 1 p.p.m. for the smaller ones. Doses were calculated from volume discharges at the outfall at the lower end of the river or mouth of the tributary. The " backstop " dose at the head of the river was calculated from a measured point on the dosed section. When several points were dosed along a river, the dose was calculated from the flow at the next point downstream. The smallest streams, of 1-2 cusecs, were given a token treatment of 2-4 pints [3] of Arkotine, thus ensuring an overdose. When the discharge of the larger rivers had decreased appreciably (e.g., the Yala decreased to 175 cusecs in 3 months) the dosage rate was raised from 0.5 p.p.m. up to 1 p.p.m.

NEEDS FOR FURTHER BASIC AND OPERATIONAL RESEARCH

Since populations of black-flies belonging to the *S. neavei* complex (Freeman, 1957) are often geographically isolated, especially in East Africa, more exact characterization of subspecies or species would appear necessary. Morphological and biological studies can shed some light, but the most exact information may be obtained from cytogenetic studies of the salivary-gland chromosomes, as has been used with such success in separating the Canadian species of *Simulium* (Rothfels & Dunbar, 1953). These genetic studies would reveal population isolates within which differences in bionomics might be sought, and provide evidence for that geographic isolation so favourable for eradication operations.

There is a need for precise identification of the freshwater crab hosts of the *S. neavei* complex. For example, on the Uganda side of Mount Elgon the small dark upland crabs are identified as a species close to *Potamon beradi*, while on the Kenya side they are mainly *P. granviki*. The principal host of *S. neavei* in the Stanleyville-Lumami region is a species of *Potamon* as yet unidentified.

In any operations in a new area, it is necessary to know the length of the larval period, since this determines the interval between dosing cycles. For example, the reinfestation of the Yala river in Kenya was considered to be due to the fact that a 14-day dosing cycle had been employed under the impression that the larval period was 16 days; the infestation was then eliminated with a 10-day dosing cycle. The duration of the larval stage on the Uganda slopes of Mount Elgon was determined as 13-16 days at an average stream temperature of 19°C.

Dosage intensity is important, since high concentrations of DDT are more expensive and introduce the hazard of fish kill. At the dosage rate of 5 p.p.m. DDT initially used in Kenya, fish kill was conspicuous. At 2.5 p.p.m., certain fish became moribund, but there was no considerable kill. At 0.5-1 p.p.m., no effect was seen on fish, nor indeed on the crabs. Headwaters of the streams in the highlands were treated at 0.1 p.p.m. to avoid killing game trout, and this dosage destroyed the *Simulium* larvae. However, on some rivers in Kenya a dosage of 0.25 p.p.m. did not always obtain complete control.

Field workers have expressed the need for small portable aliquots of DDT in some form to apply to the headwaters of small streams or to isolated rapids of low-water rivers. Plaster blocks [4] containing DDT may be made in the following manner: to 500 ml of a 25% emulsifiable concentrate is added 1 kg of plaster of Paris and 250 ml of water, and from the mould (12 inches × 2 inches × ¾ inch deep), which includes 4 lengths of string (to anchor the block in the stream), there are cut 4 blocks, each 3 inches × 12 inches × ¾ inch and containing 31 g of DDT. The range of larvicidal effectiveness of such blocks is less than a mile (Jamnback & Collins, 1955). Bags of wood shavings impregnated with DDT in oil and enclosed

[1] Imperial gallon = 4.5 l.

[2] 1 inch = 2.54 cm.

[3] 1 pint = 0.56 l.

[4] Described by G. Prevost, Department of Zoology, University of Montreal, Canada, in a mimeographed bulletin available from the author; redescribed by Jamnback & Collins (1955).

in cheesecloth bags (Hocking, 1953) or vermiculite similarly impregnated and bagged (Barnley, 1958) have proved inferior to liquid doses. Gelatin capsules [1] enclosing 5 ml of an oil solution containing 12% DDT and 4.5% gamma-BHC are available in several grades of gelatin for different water temperatures and rates of release. Approximately 12 of these capsules would be required to treat a 1-cusec stream at 1 p.p.m./30 min. Pastes of DDT that may be subdivided and moulded by hand are available, either with colloidal DDT in a non-water-soluble liquid (Murphy paste) or with DDT incorporated in soluble wax.[2] In Guatemala, very small streams of up to 0.25 cusecs have been dosed with DDT emulsifiable concentrate carried in 4-ml vials (Dalmat, 1958); the contents, in units sufficient for 0.05 cusecs or for 0.25 cusecs, are added to a canful of stream-water and siphoned into the stream.

CONTROL OR ERADICATION OF *SIMULIUM DAMNOSUM*

ERADICATION OPERATIONS IN UGANDA

The principal infested areas in the Protectorate were the Victoria Nile from Lake Victoria to Lake Kyoga, the Murchison Nile from Atura to Lake Albert, and the lower reaches of the rivers draining the Ruwenzori Mountains (Fig. 1). *S. damnosum* is also considered to be probably present at Nimule on the Albert Nile at the Soudan border, on the lower reaches of the rivers in West Nile province, and near the mouth of the Nkusi River (Barnley & Prentice, personal communication, 1960).

The Victoria Nile (approximately 17 000 cusecs) was treated in 1952 with DDT at 0.4 p.p.m./30 min. applied in 12 weekly applications above the Ripon Falls (Barnley, 1958). A launch travelled to and fro across the river as water was taken in and diluted with emulsion concentrate by means of a fire-fighting pump. By the third application, adult *Simulium* had disappeared. The numbers of flies remained low for 3 years after the treatment. Onchocerciasis had afflicted 99% of the inhabitants on both sides of the 45-mile stretch of rapids. After the treatment this region became more densely settled, particularly on the eastern shore, and land values rose.

In 1956, since it was becoming apparent that the surviving population of *S. damnosum* might be completely eradicated, the river was again treated with DDT at 0.2 p.p.m./30 min. in 10 weekly applications. The formulation—12.5% DDT in an equal mixture of Diesel oil and kerosene—was applied to the overflow spillway of the Owen Falls dam at Jinja, being contained in a water cistern supplied with a pipe and tap on the upstream side of the dam. No adult *S. damnosum* appeared in the 4 years after treatment, but a few larvae were found in the spillway of the dam in late 1960, which could easily be eradicated by a further treatment. The only existing population of *Simulium nili*, an unusually large species, was also eradicated.

The Murchison Nile (approximately 20 000 cusecs) was treated in 1959 with DDT at 0.2 p.p.m./30 min. applied in 11 weekly treatments from January to April (the first treatment being 0.2 p.p.m./60 min.). The application point was at the Amenya rapids ; below it were 50 miles of rapids and the Karuma and Murchison Falls. The formulation, similar to that previously used and without emulsifier, was applied from a boom of perforated polythene pipe, 490 feet long, suspended across the river by means of a transmission wire running between two transmission towers. The cost of the 6000 gallons of insecticide used was 100 000 EA shillings, and that of the two towers (erected by the Uganda Electricity Board) was 40 000 EA shillings. After the second application the fly count, which had averaged 20-30 per hour, fell to zero. However, by July the flies reappeared, and by October large numbers of larvae were found in a tributary, the Aiago river. Examination in August 1960 showed that a large population of larvae had returned to the Nile.

That the Aiago river is probably a major source of infestation is indicated by the 40% prevalence of onchocerciasis at Koitch and Bobi at its headwaters. Other tributaries such as the Murchison river and the Kiba river may also be breeding-places, and possible infestation on the Aswa river may link up with the river populations in the West Nile district. It is exceedingly difficult to examine or dose these

[1] Manufactured under the name of "Tossits" by Wyco International, 4811 Carnegie Avenue, Cleveland 3, Ohio, USA.

[2] Manufactured by the Agricultural Chemical Division, Sun Oil Company, 1608 Walnut Street, Philadelphia 3, Pa., USA.

tributaries, since they are in the Murchison Game Park, where travel through the high elephant-grass is particularly difficult and hazardous owing to buffalo and other big game, and because of the absence of bridges. These tributaries have been examined from a Caspair light aircraft, and experimental dosings have been made with full beer-cans dropped from a special bomb chute in an Auster aircraft (Barnley & Prentice, personal communication, 1960).

CONTROL OPERATIONS IN NIGERIA

Larvae of *S. damnosum* develop in all the rivers of Northern Nigeria except those in the dry extreme north beyond latitude 11°N; the species is also absent from the Gongola plains and the Benue valley (Crosskey, 1956). There are 5 other species breeding in the rivers (Table 1), but they do not bite man; *S. bovis* is known to bite man, and may possibly be a vector. For most of the year the rivers are bare sand or rocks with pools and small cascades; after the rains commence in May or June they fill and discharge strongly till October. The peak of adult *Simulium* intensity is reached in August and September, which is the peak of onchocerciasis transmission.

There are about 350 000 people suffering from onchocerciasis in Nigeria, of whom some 20 000 are blind; excessive skin irritation precedes failing sight (Budden, 1956). The prevalence exceeds 50% in the Abuja and Pawa river areas south of Kaduna, at Lokoja at the confluence of the Niger and Benue rivers, and at Beli and Harwal river in the Adamawa region.

At the request of the Emir of Abuja, a *Simulium* control scheme was inaugurated in 1955 over an area of 1200 sq. miles around Abuja Town, including the Tapa, Iku and Osuman rivers, tributaries of the large Gurara river, which flows into the Niger (Crosskey, 1958). The first treatment was made in 1956 with DDT at 1.4 p.p.m./30 min. in 12 weekly applications at 4 points, at the end of the dry season —i.e., from February to April. In subsequent years the applications were made at 7 points (4 being on the Osuman), and the dosage was reduced first to 0.5 p.p.m./30 min. and finally to 0.5 p.p.m./15 min. After using a solution in Diesel oil in 1956 and 1957, subsequently a 25% emulsifiable concentrate (Didimac 25, I.C.I.) was employed. Estimates of adult density were made by " fly-boys " collecting from their legs for 15 minutes. The results, expressed in adult flies per boy per hour (f.b.h.), during the June and July following the application were as follows:

	1955	*1956*	*1957*	*1958*	*1959*	*1960*
Flies, f.b.h.	5.8	0.15	1.2	0.15	0.42	0.15
Dosage, p.p.m./min.	—	1.4/30	1.0/30	0.5/30	0.5/30	0.5/15

The poor results in 1957 were due to the rivers being exceptionally low at the time of application. In 1958 and subsequently the treatments were made in rising rivers from June to August, and required more

TABLE 1
LARVAE OF *SIMULIUM* (BESIDES *S. DAMNOSUM*) COMMONLY FOUND IN RIVERS AND TRIBUTARIES IN AFRICA [a]

Simulium species	Uganda	Northern Nigeria	Southern Cameroons	Northern Ghana	Sierra Leone	Upper Volta
griseicolle	+			+		+
adersi	+	+		+		+
medusaeforme [b]	+	+		+	+	+
cervicornutum	+	+	+		+	
unicornutum		+	+	+	+	+
impukane		+				+
ruficorne				+		+

[a] In addition: in Northern Nigeria, *kenyae*, *schoutedeni*; in Sierra Leone, *johannae*, *loutetense*, *rodhaini*.

[b] Form *hargreavesi*.

insecticide. During this period the Wuye river, a tributary of the Osuman, becomes infested and is then treated also.

The insecticide exerted its effect for 15-23 miles below each application-point, the main sources of loss being tree-trunks and roots, and fishermen's dams; these latter were the cause of the single instance of fish kill, which occurred in 1956 only. Repopulation of the rivers with moderate numbers of larvae was noted some 6 months after the applications. The reinfestation is considered to originate from flies travelling upstream and not cross-country from neighbouring rivers, since the catches reappear first along the river and not in the intervening country.

The cost of the annual operation, exclusive of the salaries of permanent staff, was about £WA1100 [1] (approximately £WA1 per sq. mile). Nearly half of the first year's cost (£WA400) was for making roads at approximately £WA25 per mile. Another initial cost was a Watts current meter at £WA140. Expensive constant-flow application equipment could not be obtained or made in Africa. Instead, the 4-gallon kerosene tin, punched with a 4-inch nail, was found completely satisfactory. It was slung from a pole with rope and carried into the shallow river-bed by two men; other workmen filled tins with a mixture of the DDT emulsion and water and poured it into the delivery tin, which emptied its entire contents in 15 minutes.

The prevalence of onchocerciasis in the Abuja area had been found by Crosskey to be 83% by skin-snip survey. In 1956 Henry found it to be 55%; a similar resurvey in 1960 showed it to have dropped to 31%. The greatest reduction (of 60%) was in the lowest age-group (under 9 years); however there were still occasional cases of infection incurred at ages below 5 years. Onchocerciasis decreased most in villages more than 6 miles distant from the rivers, suggesting that here the adult reduction had fallen below the threshold of density required for transmission. The Abuja scheme, being one of control within a generally infested region, must now be continued annually, and represents a persistent but legitimate claim of this area on the funds of the Ministry of Health of Northern Nigeria; the cost in 1960 was approximately 10/- per head of population protected (Davies et al.[2]).

Since the prevalence of onchocerciasis in villages around the capital town of Kaduna ranged up to 100%, applications were instigated in 1956 on the Kaduna river. They were made in 12 weekly treatments of DDT at 0.5 p.p.m./30 min. between February and April, when the discharge was of the order of 450 cusecs, and applied at Kurmin Kaduna, 6 miles upstream of the town. The series of treatments were continued until 1958, reduced to a single treatment in 1959, and discontinued in 1960. The population density of adult flies, which in 1955 ranged up to 30 f.b.h., has remained low in 1960. It would appear that there is little source of reinfestation in the quiet reaches of the river above Kurmin Kaduna. Below Kaduna the river is full of rapids for some 120 miles down to Zungeru. Halfway in this stretch is the Shiroro gorge, where breeding of *S. damnosum* remains extensive.

Protection of the town of Lokoja, where onchocerciasis is prevalent, was inaugurated in 1958 with a series of treatments applied to cover 25 miles of breeding-sites of *S. damnosum* on the Mimi river.

A future project is the Harwal river scheme, formerly shelved in favour of the Abuja scheme because the maps were better in the latter district. This area, along with the Loko-Song region, located as it is in extreme north-eastern Nigeria, is apparently an isolated district enclosed by the non-breeding regions of the Gongola and Benue rivers and by the northern limit of *S. damnosum*. There are some 20 000 persons in the area, of whom over half are infected with onchocerciasis; many have moved out of the area because of the fly and the disease.

In Western Nigeria, onchocerciasis has not been studied as a problem, although *S. damnosum* has been captured biting both north and south of Ibadan. In Eastern Nigeria the fly is quite abundant in the Enugu area. As a consequence, treatments of the Oji river with 10% DDT in dieseline at 5-day intervals were inaugurated in 1954 and repeated for at least 3 years. In the Southern Cameroons onchocerciasis is prevalent and is studied at the laboratory at Kumba; DDT larvicides have been applied at Tiko. However, the streams of this mountainous district contain less *S. damnosum* than other species (Table 1).

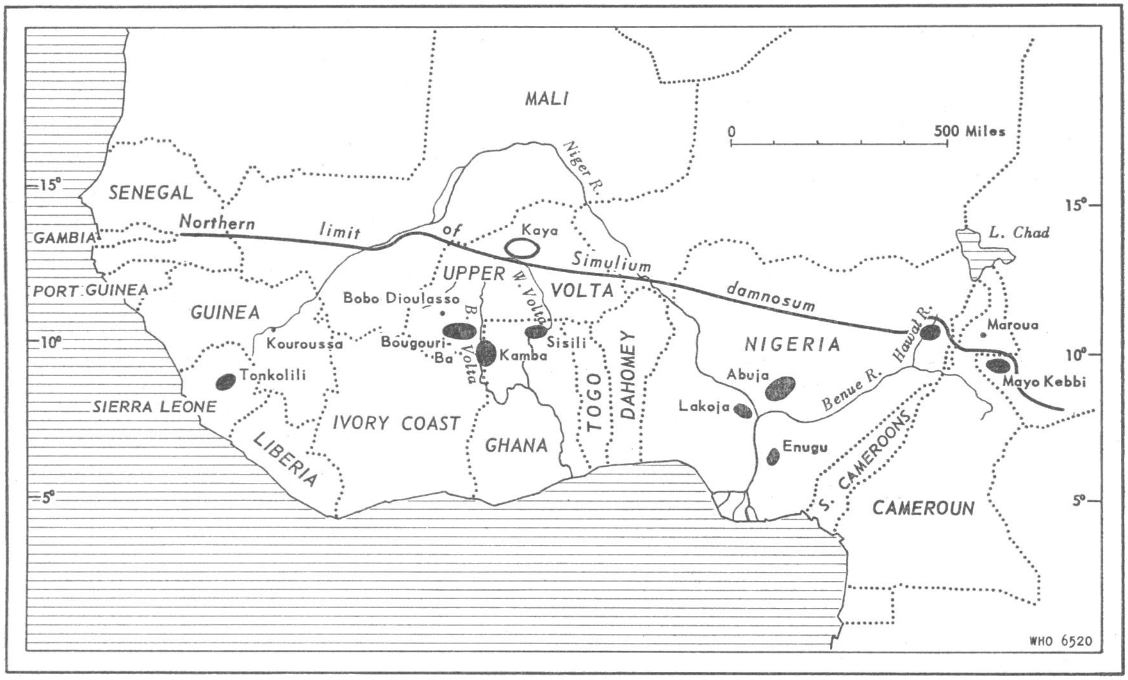
CONTROL OPERATIONS IN GHANA

In this country, onchocerciasis reaches its highest level in the northern territories, where the prevalence ranges from 80% to 100%, and parasite rates in *S. damnosum* are approximately 12%. Breeding occurs in the Black, White and Red Voltas and their

[1] £ West African 1 = US$2.80.

[2] See the article on page 491 of this issue.

FIG. 2
DISTRIBUTION OF *SIMULIUM DAMNOSUM* IN WEST AFRICA



tributaries. The situation is similar in Upper Volta in the north, and in Dahomey to the east, which forms a link with Northern Nigeria (Fig. 2).

The first control experiment was performed in 1954, when the Kanyanbia and Sisili rivers, tributaries of the White Volta, were treated in the rainy season in July and August (Crisp, 1956). At 4 points on the Kanyanbia and 2 on the Sisili, 7 applications were made at 4-day intervals with a dose of 10% DDT solution in fuel oil, equivalent to 0.1 p.p.m./15 min. The formula of Hocking (1953) was employed to calculate dosage from the speed and size of the stream. The result was a reduction in the fly count of about 70% in August only, followed by a rapid reinfestation, the untreated tributary streams being held responsible.

Meanwhile in 1954 and 1955, field experiments were performed with a mixture of 1 part 10% DDT/kerosene solution, 1 part soap and 10 parts clay (Noel-Buxton, 1956). Applied to the Kamba river (380 cusecs) at a DDT dosage of 0.03 p.p.m./23 min., it achieved complete control of *S. damnosum* as far as the mouth of the river 24 miles away. Applied to the Black Volta (1600 cusecs) at 0.044 p.p.m./30 min. it obtained complete control at 50 miles' and 45% control at 100 miles' distance. This stretch of the river being without tributaries, 4 more applications were made at 4-day intervals in January, and obtained elimination of all flies by March, after which larvae gradually became re-established in the river. Unfortunately these experiments did not show whether inferior results are obtained without the clay admixture.

In an experiment with DDT applied at 0.1 p.p.m./30 min. from a Didimac emulsifiable concentrate to the Black Volta in 1959 (J. D. M. Marr, unpublished data), complete control was obtained for 50 miles downstream. The same dosage applied from a 10% solution in fuel oil to the Red Volta in 1957 obtained only 50% control. During 1959 and 1960 applications at 0.1 p.p.m./30 min. were made from a Didimac emulsifiable concentrate to the Sisili river during the rains, to the Kamba river after the rains, and to the Black Volta during the dry season (J. D. M. Marr & G. K. Naomesi, unpublished data). On the Sisili it was found that the adult *Simulium* population was not significantly reduced, since the tributaries were not treated.

CONTROL OPERATIONS IN SIERRA LEONE

The entire country is infested with *S. damnosum*, with the notable exception of the sierra itself around Freetown, and the southern coastal plain. It is drained by nine rivers, each with a dry-season discharge of 1000-10 000 cusecs at the downstream limit of breeding. The prevalence of onchocerciasis was found by Blacklock to be 50% at the diamond mines at Tumbodu on the upper Rewa, and by Mills to be 30% at the iron mines at Marampa on the Seli river. The prevalence of impaired eyesight is not high, being 1.6% at Farangbaia. The fly density ranges up to 250 f.b.h. at Port Loko, near the lower Seli, where the parasite rate was approximately 8%. The parasite rate at Marampa was found to be as high as 13%.

The most severe problem was encountered on the Tonkolili river, a tributary of the Seli, where an iron mine is being developed. The onchocerciasis prevalence among the African staff was 53%, and in the African population it was as high as 85% (Conran & Conran, 1956); there were 3 cases of onchocerciasis among the Europeans there. The parasite-rate was 7%, and the average *Simulium* density was 23 f.b.h. in September (wet season), falling to about 10 f.b.h. in the dry season (Lewis, 1956; Lewis, 1958).

Insecticide treatments were commenced in April and May 1957, with 7 treatments of DDT at 1 p.p.m./30 min. applied every 10 days to the river and to its tributaries. The work was done by surveyors, who are especially exposed to infection; unfortunately no fly-density counts were taken before and after the treatment. The Tonkolili river itself is 37 miles long and flows between high hills; its discharge is 100-700 cusecs in its middle course and 400-1000 cusecs at its mouth.

Systematic treatments were later inaugurated by Crisp (unpublished monthly reports, 1957-59); finding an average density of 10.7 f.b.h. in September 1957, he applied a series of fortnightly DDT treatments at 1 p.p.m./30 min. from December 1957 to March 1958. This application, performed during a decline in the fly population as the dry season progressed, resulted in a density of 1.0 f.b.h. in March and 0.5 f.b.h. in July 1958. Three tributaries were found to contain a few *S. damnosum* in November 1958; they were treated with DDT, and this species has not reappeared in them since that date. However the first larvae reappeared in the main river in June, and by October the fly density had risen to 6.7 f.b.h.

Applications were resumed in December 1958 and continued every 2 weeks for an entire year, until December 1959. They were initially made at 4 points along the river at the rate of 1 p.p.m. of DDT; in August 1958 the rate was changed to 0.5 p.p.m., applied at one point (Wakal) where two tributaries joined to form the beginning of the Tonkolili. As a result the fly density from September to December 1959 stayed at the low level of 0.7-0.8 f.b.h. The parasite rate in the fly was also reported to have fallen to 1%-2%. On cessation of dosing in February 1960 the density rose to 6.2 f.b.h. in May; new fortnightly treatments at 0.5 p.p.m. started in June curbed the density to 1.5 f.b.h. in July and August 1960. These treatments are being continued, the expenditure, every fortnight, on 15 gallons of a 25% emulsifiable DDT concentrate (Didimac 25) reaching approximating £WA400 per year. The applications are made from a 5-gallon constant-flow dispenser of commercial type (Candy Filter Company, London).[1]

The main sources of reinfestation are the fly populations developed in the Seli river, which runs parallel to the Tonkolili, within 5 miles at its nearest point. The Pampana river flowing 10 miles to the south of the Tonkolili is also a source of reinfestation, possibly through two of its northern tributaries, which rise close to the bend of the Tonkolili. The Seli river was treated from January to March 1959 with 9 doses of DDT at 1 p.p.m. applied 1 mile above Bumbuna and again 4 miles below that town. The Pampana was treated at Masanga in November and December 1958 and January 1959. The fly counts at Bumbuna did not indicate that a reduction had been achieved, but a marked reduction in fly density was noted in a general way at Masanga.

CONTROL OPERATIONS IN THE CONGO BASIN

Onchocerciasis transmitted by *S. damnosum* posed the most serious problem at Léopoldville, where fifteen years ago 100% of the African population was infected, with 5% blind, and 45% of the resident Europeans had the disease (Wanson, Courtois & Lebied, 1949). The parasite rate in the adult fly population was 16%. The larvae bred in the rapids of the Congo, when the river was low from June to August. They were found attached not only to rocks, but also to *Pennisetum* (horse-tails) and to

[1] Control of *S. damnosum* throughout the Tonkolili valley had been established by the end of 1960 (see AFR/Onchocerciasis/A-4, 1961, unpublished working document for the Second Conference on Onchocerciasis, Brazzaville, 1961 convened by the WHO Regional Office for Africa).

floating masses of *Echinochloa*. The adults would roost on vegetation on the islands in the rapids, the males clustering on the flowers of *Baphia*; their density reached a peak in August and September.

The massive discharge of the Congo, which even in low water is 1 000 000 cusecs, made it impossible to add larvicide to the river as a whole. Adult control was first attempted by dusting the vegetation in the most heavily infested suburbs with 10% DDT dust at 20 kg/hectare; it proved entirely ineffective. An Oxford aircraft was therefore engaged and a DDT aerosol was produced by injecting a 20% DDT solution, in 3 parts xylene and 7 parts gas oil, into the exhaust stack. The eastern river bank, the islands in the rapids, and the western river bank were treated at 20 mg DDT per sq. mile between September and December 1948, and a virtually complete kill of adult flies and of larvae in the river was obtained. In March and April 1949 it became necessary to treat the Ndjoué, Luwa and Zumune rivers on the west side, since they were the source of flies repopulating the Congo islands. This resulted in an apparently total elimination of *S. damnosum* from the district, the nearest point of breeding elsewhere being 100 km away at the Crystal Mountains.

However, ten years later the city of Léopoldville was still being kept free of *S. damnosum* only by continued annual applications. These were accomplished by the use of helicopters, and 4% BHC was substituted for DDT as an exhaust aerosol. The most difficult problem was the Ndjoué river on the west side, in which infestation persisted despite aerial treatment of its lower 10 km annually until 1952. Since 1952 annual applications have been made on the eastern side as part of the scheme to control *Anopheles gambiae*; during the period only some 20 flies a year have been discovered at Léopoldville, and these are considered to have originated in Ndjoué. But the number of new cases of onchocerciasis in Léopoldville since 1949 has been zero. After the installation of a dam 2 km above its mouth, the Ndjoué was treated in 1959 by adding larvicide to the reservoir. However, this river became repopulated in 6 months and by 1960 the adult density was very high. With a parasite rate of 4% and a high prevalence of onchocerciasis in the African population along the Ndjoué, this focus remains a serious one.

Elsewhere in Congo there are five other foci of onchocerciasis transmitted by *S. damnosum*—namely, Lomani, Sankuru, Inzia, Uele and Kivu (Lebrun, 1954). For river treatments a regime of 12 weekly applications of DDT at 0.12 p.p.m./30 min. has been recommended, to start and finish with the beginning and end of the high-water season. Control of *S. albivirgulatum* and *S. faini*, two small non-vector species which breed in the small rivers around Léopoldville and attack man and animals, was achieved with single treatments of gamma-BHC at 1.5 p.p.m./30 min. The adults became greatly reduced in numbers the day after the treatment, and disappeared completely after 6 days; however, after 10 days the treated rivers became reinfested with larvae (Wanson, Courtois & Bervoerts, 1950).

OPERATIONS IMMEDIATELY SOUTH OF THE SAHARA

The regions of highest prevalence of onchocerciasis lie in a belt between latitudes 9° and 13° N, including Mayo Kebbi in Chad, Maroua and Foumban in Cameroun, northern Dahomey, northern Togo, northern Ivory Coast, along the Black, White and Red Voltas from Atakora to Banfora in Upper Volta, the southern tributaries of the Niger in Soudan, its headwaters at Kouroussa in Guinea, and eastern Senegal. Onchocerciasis is absent from southern Dahomey and southern Ivory Coast (Masseguin, Taillefer-Grimaldi & Leveuf, 1954).

The first insecticidal attack was made in 1955 on the Mayo Kebbi, where *S. damnosum* bred in a 55-km stretch extending upstream from Tessoko to the entry of the Mayo Ligam (Taufflieb, 1955). This is an isolated fly population, the nearest neighbours being 10 km to the south, on the Mayo Wemba, a tributary of the Benue river. Most of the larvae were found at the mouth of the Ligam and at Birimi, mainly on vegetation and immersed branches of trees; adults accumulated between these points at the mouth of the Mayo Ledde and at the Chutes Gauthiot, where they were in excess of 400 f.b.h. in the evergreen vegetation. The Mayo Kebbi was treated in the dry season, when the flow was only 8 cusecs; between 15 February and 1 April it received 6 successive applications at 3 points of gamma-BHC at 1-2.5 p.p.m./30 min. The treatment was applied by mixing 1 part of a 15% lindane emulsion concentrate (Pechinery-Progil) with 1 part of clay or laterite and 5 parts of water. During the same period 10 adulticide applications were made along the Mayo Kebbi with 2% lindane in gas oil emitted as aerosols from the exhaust stacks of two Bell helicopters. The larvae completely disappeared by 21 February and the adults by 1 March.

Despite much fish kill, eradication of *S. damnosum* was not achieved, since the flies returned in the wet season. The reason for the failure is still unknown. There was a stretch of 15 km above the Chutes Gauthiot, and 20 km below the Ligam dosing-point, which was too inaccessible to be checked. Although the tributaries (Mayo Ligam, Ledde and Tam) were not treated, they were completely dry at the time. Treatments were therefore continued from 1956 to 1958, gamma-BHC being applied at weekly intervals in " crash " concentrations of 3 p.p.m./1 min. In 1959 it was replaced by DDT at 6 p.p.m./1 min. The inability to achieve eradication of *S. damnosum* at Mayo Kebbi is considered to be due either to a very fast larval development, or to survival in rapids sequestered on one side of islands in the treated river, or to drought-resistant eggs or other stages of the fly.[1]

Preparatory work has been conducted by the Organisation commune de Lutte contre les Grandes Endémies, involving the governments of Dahomey, Togo, Ivory Coast, Upper Volta, Niger and (possibly) Guinea, under the aegis of the Office de la Recherche scientifique et technique Outre-Mer, with operational headquarters at the Centre Muraz, Bobo-Dioulasso (Upper Volta). Surveys have been made since 1956 of the epidemiology of onchocerciasis, biology of the vector, and hydrography of the rivers. Special foci include Bougouni and Koutiala in Sudan, and Oedougou, Koudougou and Banfora in Upper Volta, as well as Kaya, located at latitude 13°N and possibly an isolate of *S. damnosum* (Fig. 2). Preliminary insecticidal experiments have been made on the Bougouri-Ba, a river running south-east from Bobo-Dioulasso to join the Black Volta. This river, 400 km long, flows at approximately 70 cusecs in the dry season and at 3500 cusecs in the wet season.

Experiments were made in 1957 with DDT described as a 17% solution in kerosene. The solution was mixed with water and applied from 15-gallon cylindrical tins pierced with holes. Single applications at 2.5 p.p.m./30 min. were applied in the dry season at 3 different rapids on the Bougouri-Ba (Blanc et al., 1958). They were effective in eliminating larvae downstream, and the effectiveness would carry over slack water 200 m in length, but not over calms 500 km long. Some fish were killed, the mortality being ascribed to the kerosene; in this region fish are caught as a source of food.

[1] *Rapport sur l'onchocercose au Mayo-Kebbi. Mise-au-point, 1959-1960, Secteur N° 2, Bongor,* by Méd.-Cap. Louis, République du Tchad, Ministère des Affaires sociales, Direction de la Santé publique, Service de Lutte contre les Grandes Endémies (unpublished mimeographed document No. 328, DSP/LGE).

REQUIREMENTS FOR A SUCCESSFUL CONTROL OPERATION

For control or eradication of *S. damnosum*, larvicidal operations are the best method of attack, and the best insecticide is DDT. Although certain cyclodienes such as heptachlor are effective at lower doses, gamma-BHC can kill new pupae, and parathion may be more effective in slow-moving water, those who have investigated this question in Guatemala (Dalmat, 1958) and in Canada (Hocking, 1953) agree that DDT is the insecticide of choice. With DDT for *Simulium* larvae we have the perfect weapon for the perfect target.

The most suitable formulation is an emulsifiable concentrate, simply because it carries the most DDT (up to 25%) in liquid form; it is mixed with about 3 times its volume in water before application. Solutions of DDT in fuel oil, gas oil or kerosene may spread more rapidly across the river, but without auxiliary solvent they can carry no more than 10% DDT. Although a gas oil solution proved very effective in Sierra Leone, it was found more convenient to return to a ready-made emulsifiable concentrate (Crisp, unpublished monthly reports, 1957-59). The specific gravity of the formulation has been considered important, particularly when applied as a solution unmixed with water, a sp. gr. of 0.84 being advocated by Lebrun, and of 0.98 by Ovazza, by McMahon and by Barnley. Experts in New York State take a 20% DDT solution in heavy aromatic naphtha, and dilute with kerosene to a sp. gr. of 1.00; they also add Triton-X-100 emulsifier to aid mixing in the stream and penetration into protected spots (Jamnback, 1960 [2]). Excellent control over long distances in Canada has been obtained with a 30% DDT concentrate in methylated naphthalene (no emulsifier) at a sp. gr. of 1.04 (Fredeen at al., 1953). Since such solvents spread less rapidly than lighter oils, some attention should be paid to ensure that the concentrate is mixed with the water for the entire width of the river.

Special formulations of DDT admixed with clay were developed in Ghana because of a Canadian report (Fredeen, Arnason & Berck, 1953) that DDT was more effective when adsorbed on suspended clay particles in the river. A second application made on the South Saskatchewan river in July, when the

[2] In: *Proceedings of the 2nd Canada-U.S. Conference on Blackflies, September 23-24.* (Copies available from: D. G. Peterson, P.O. Box 248, Guelph, Ont., Canada.)

turbidity was low, had proved less effective than the first application in May, when there were three times more suspended solids (Fredeen, Arnason et al., 1953). However, these same workers found in later experiments (unpublished) that wettable powders were not superior to emulsions or solutions, and that pulverized granules of DDT in bentonite were unsatisfactory, since they settled out. Good larval control may be obtained with DDT/oil formulations in eastern Canada where the streams are perfectly clear, and Barnley has obtained complete control for 17 miles in streams draining the Ruwenzori Mountains (Uganda) with DDT in oil solution at the highly economical dose of 0.05 p.p.m./30 min. It may be concluded that clay formulations are unnecessary.

A dosage rate that is reliable for effective control and has negligible effect on fish may be taken as 0.5 p.p.m./30 min. A rate of 0.1 p.p.m. is reliable for large rivers, and probably for many of the smaller ones. When logistics dictate that applications must be made at many points during a day's work, it is possible to reduce the 30 minutes' period of dosing to 15 minutes or less, and very small doses may be simply poured in; it is, however, assumed that the larvicidal effectiveness will be checked the first time that this economy in time is attempted. In most cases any control failures will be found to be due not to insufficient DDT concentration nor to too short a period of application time, but to non-carry in slack reaches or to diversion of the treated water on one side of islands.

Experience has shown complicated application equipment to be unnecessary. Any metal container in which a hole or holes may be punched is satisfactory. In many parts of Africa the 4-gallon kerosene tin is available. Special dispensing apparatus (Hocking, 1950) has at present proved unfeasible to make in most African centres. However, when applications are made from one point only at regular intervals in a control scheme (see under Sierra Leone, p. 520), a commercial constant-flow dispenser may be permanently installed there, although again it is not absolutely necessary.

It is considered that the Harwal river scheme in Northern Nigeria may be based on the use of plaster blocks of DDT, since the treatments will be carried out in the dry season, when the discharge rate has fallen to about 1 cusec. Commercial 1-lb.[1] blocks[2] of plaster of Paris and sawdust were tested in Sierra Leone and found to have no effect beyond 2 miles downstream. In the dry bed of the Harwal river, however, it is entirely feasible to drop blocks every half or quarter of a mile. For rivers that are inaccessible owing to lack of roads and abundance of big game, as in Uganda, an aircraft bomb and chute has been developed (Barnley & Prentice, personal communication, 1960). The container, filled with DDT emulsifiable concentrate, is a 1-pint plastic-lined tetrahedral milk carton.

When regular treatments are made with DDT in oil solution, the interval between applications, which normally ranges between 7 and 14 days, is dictated by the length of the larval period; certainty on this point requires figures relating water temperature to developmental rate. The number of repetitions depends on the period over which adults remain present in the area. On the Victoria Nile adults had disappeared by the third application, in Nigeria adults were immigrating from neighbouring rivers for 12 weeks, while in Sierra Leone it is considered necessary to dose the year round.

Where the series of applications is made once a year, the question arises whether it should be made in the dry season or the wet season. Some rivers swell to such an immense discharge that it would be prodigal to treat them in the wet season. Other rivers shrink in the dry season to such an extent that the DDT is not carried downstream, and the target population is negligible. Treatment at the beginning of the dry season, when the rivers are falling, is unwise since either new breeding-sites in broken water are constantly being exposed, or alternatively application in a period of falling population does not allow the effect of the treatment to be ascertained without doubt. If one season is to be picked as the most desirable, it is the beginning of the wet season, when rivers are sufficiently swollen to give adequate carry of the insecticide, and before their volumes increase out of hand. However, in some regions this may be a difficult period owing to the occurrence of flash floods which quickly return to low water. Here the usual solution is to dose as soon as the carry has become satisfactory.

The methods of determining volume flow, and thus the amount of DDT to be applied, are fully described by McMahon (1957b). In a control scheme where applications are made every year it is advisable to install water-level gauges; these gauges may be found on some bridges and it is advisable to keep them in good repair and to obtain the volume-flow equivalents from the topographic engineers.

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[1] 1 lb. = 0.45 kg.

[2] Deestan Special Blocks, Standard Disinfectants Ltd, London, England.

TABLE 2

VOLUME DISCHARGES OF REPRESENTATIVE RIVERS AND THE DOSAGES REQUIRED FOR ONE APPLICATION AT 0.1 p.p.m./30 min.

River	Discharge (cusecs) [a]	For each 0.1 p.p.m./30 min.	
		lb. technical DDT [b]	gallons of concentrate [c]
Yala (Kenya), dry season	175	2.8	1.1
Tonkolili (Sierra Leone), dry season	300	4.8	2.0
Kaduna (Northern Nigeria), dry season	450	7.9	3.0
Black Volta (Ghana), dry season	1 600	25.6	10.0
Victoria Nile	17 000	272	108
South Saskatchewan (Canada)	35 000		
Congo (at Léopoldville)	1 000 000		

[a] In the English usage, 1 cusec equals 1 cubic foot per second. In the French usage, 1 cumec equals 1 cubic metre per second, or 35.3 cusecs.

[b] Figures are obtained by multiplying the cusecs by 0.016 to obtain the lb. of technical DDT containing 70 % of the p,p′ insecticidal isomer.

[c] Figures are an approximation of the gallonage of 25% emulsifiable concentrate for each 0.1 p.p.m. required. For 0.5 p.p.m. multiply the figure by 5. One gallon of concentrate costs approximately £1 sterling (US $2.80) at African ports.

Reconnaissance of the full length of the river is desirable, preferably by air, in order to discover the existence of slack reaches, below which another dosing-point will be necessary. It is often difficult to enter the river to assess *S. damnosum* larval populations before and after the applications, and here artificial larval harbourages may be introduced, such as palm fronds or metal cones (Wolfe & Peterson, 1958). Adult populations are simply assessed by " fly-boys " standing in one place for one hour; the population level at which onchocerciasis transmission may be considered to be controlled is uncertain, but might be provisionally taken as 1 or 2 f.b.h.

Control operations are undoubtedly effective, but represent a continuing annual expenditure. In certain regions—e.g., at Kaduna in Northern Nigeria—the amelioration appears to approach the permanent, so that fly populations remain low even when operations are discontinued. In other more heavily infested regions, it is possible that extension of the area treated for the same financial outlay might be more conducive to permanent improvement. The cost of insecticide depends on the volume flow of the treated rivers. The amounts of 25% emulsifiable concentrate required for each one of the series of applications is tabulated for rivers of varying sizes (Table 2); the present cost is approximately £1 sterling (US $2.80) per gallon of the emulsifiable concentrate.

NEEDS FOR FURTHER BASIC RESEARCH

Certain information on the life-cycle of *S. damnosum* can be obtained only if it is taken into rearing. The larvae of this species have been laboratory-reared at the Liberian Institute for Medical Research, Harbel (Muirhead-Thomson, 1957), and by Mr F. N. Wright in Accra. Rearing methods for the Canadian species has also been fully reported (Fredeen, 1959). The difficulty impeding continuous colonization is in obtaining mating and oviposition. Outdoor rearing facilities, similar to the steep rocky sluice supplied with mains water installed at the Medical Entomology Laboratory, Kampala (Uganda), should be possible in many African centres. Artificial rearing would permit determination of the length of larval period with different water temperatures; it would also enable susceptibility-resistance tests to be carried out, for which a method has already been developed (Muirhead-Thomson, 1957).

The flight range of *S. damnosum* is really unknown, although there is a variety of observations (Freeman & de Meillon, 1953); perhaps 25 miles is a realistic figure at present. Experiments in which the flies are tagged with radioactive phosphorus by rearing the larvae in the presence of ^{32}P phosphate ion have been performed with *S. arcticum* in Canada (Fredeen, Spinks et al., 1953), but out of 500 000 larvae treated only 3 radioactive adults were recovered in the field.

The question of aestivation or interrupted gonotrophic cycle has been studied in the field by scientists from the Centre Muraz, Bobo-Dioulasso (Upper Volta). Aestivation in a drought-resistant egg stage was suggested by Hughes in 1952, but recently in Upper Volta it has been found that eggs left high and dry collapse and do not hatch (Blanc et al., 1958). It has also been found in Upper Volta that whereas before the rains all adults have disappeared, yet within 24 hours of the first rain and freshet new (white) eggs appear on the river in large numbers (Grenier, Ovazza & Valade, 1960). It has been suggested that pupae can aestivate (de Meillon, 1957). The idea, put forward by Lewis in 1953, that during the dry season the gonotrophic cycle of the adults is delayed, and that adults can persist, not biting, in crevices between rocks or in causeways, has received observational support in northern Ghana and Upper Volta. It has also been suggested in Northern Nigeria that in certain secluded places breeding continues in very small numbers throughout the dry season, and it would seem that this is the first possibility that should be guarded against in an eradication programme.

The most valuable basic research is survey of the populations of *S. damnosum* on the edges of its geographic range in Africa, with a view to discovering isolated populations separated from other breeding-areas by at least 40 miles. The population on the Victoria Nile, successfully eradicated in 1956, was a definite isolate and of apparently recent origin. The population on the Murchison Nile may be an isolate, but the situation is complicated by larval breeding in its tributaries, and the proximity of the Albert Nile and its tributaries in West Nile province. Mayo Kebbi and Harwal river on the upper Benue are probably isolates, and so is Kaya in Upper Volta; it is even possible that the Léopoldville-Djoué breeding-area is isolated. Since eradication operations are the most economical, and since they are possible only in fly populations that are isolated, the most basic research contribution would be the systematic mapping of the edges of the range of *S. damnosum* in Africa, particularly those immediately south of the Sahara.

ACKNOWLEDGEMENTS

Thanks are due to the many research and administrative personnel who supplied the material for this survey and through whose kind collaboration it was possible to visit the treated areas and to examine the control practices in great detail. These workers and officers are mentioned by name in the original mimeographed report of the survey (WHO/Insecticides/119). Special acknowledgement is made to Professors M. Giaquinto-Miro, WHO, and P. C. C. Garnham, London School of Hygiene and Tropical Medicine, for their invaluable assistance in planning the contacts to be made in the itinerary.

RÉSUMÉ

Il est tout aussi possible de détruire au stade larvaire, dans les rivières qui les abritent, *Simulium damnosum* et *S. neavi*, tous deux vecteurs de *Onchocercus volvula*, que de s'attaquer aux simulies adultes au moyen de pulvérisations insecticides. Le DDT en solution concentrée, émulsionnable, s'est révélé l'insecticide de choix dans cette indication; par ailleurs, facile à se procurer, il présente des avantages au point de vue prix et sécurité d'emploi. Il est à noter cependant que les solutions huileuses ont donné des résultats inégaux, et que l'incorporation du produit à de l'argile pulvérisé n'est pas d'un usage pratique. La concentration efficace du DDT est de 0,5 p.p.m. si le débit du fleuve en 30 minutes est important, chiffre qui doit être porté à 1 p.p.m. dans les petits cours d'eau pour compenser les pertes par absorption. Ces doses n'exercent aucun effet notable sur les poissons, et les échecs ne sont pas imputables à une posologie trop faible, mais au fait que l'insecticide cesse d'être charrié par la rivière dès que les eaux de celle-ci sont ralenties sur une partie importante de son cours. Il importe donc de choisir judicieusement les points d'immersion.

On administre le DDT à intervalles de 7 à 14 jours en fonction de la vie larvaire, car les pupes sont résistantes au produit, et pendant une période de 3 mois environ. En fait, les insectes ne vivent normalement que 3 semaines au maximum, mais il est indispensable de se protéger contre les simulies qui proviennent de cours d'eau non-traités. Les fleuves peuvent être traités aux

basses eaux afin de ménager l'insecticide, les petites rivières à la saison des pluies lorsque leur débit devient suffisant, et les ruisseaux et affluents au moment des crues.

En certains territoires du Nigeria du Nord et du Sierra Leone, la lutte a été poursuivie, respectivement, 3 mois par an et toute l'année: le nombre de *S. damnosum* capturés en une heure sur les jambes de sujets volontaires a été inférieur à 1,0 (0,15 et 0,5), et la transmission de l'onchocercose était pratiquement interrompue. En 1952 et 1956, une population isolée de *S. damnosum* a été presque éradiquée de la région du Nil à la sortie du lac Victoria. La même opération a été conduite à bonne fin au Kenya occidental, entre 1952 et 1956, en ce qui concerne *S. neavi*. La méthode suivie permet d'énumérer les facteurs de succès: a) exploration des rivières sur toute leur étendue, b) contrôle immédiat des résultats par la recherche des larves, c) relevé détaillé et enregistrement de tout ce qui concerne les rivières traitées.

La lutte contre *Simulium* pose de véritables problèmes de logistique, car elle exige des voies d'accès convenables aux lieux d'immersion de l'insecticide et de prélèvement d'échantillons. Elle doit être entreprise sur une échelle assez vaste qui tienne compte des lieux de reproduction et de l'immigration qui s'effectue à partir des territoires limitrophes. En revanche, elle n'entraîne pas de frais importants puisque le matériel utilisé se ramène à peu près à des bidons d'essence perforés au calibre voulu. Pour 12 traitements, le prix de l'insecticide revient à environ 1800 CFA. Rapportés à la superficie, les frais d'une campagne étaient au Nigeria du Nord de 264 CFA par km², et trois fois moindres dans un territoire de l'Ouganda, plus facile à traiter. A l'ouest de ce dernier pays, la présence de multiples cours d'eau fait obstacle à l'éradication de *S. neavi*; celle de *S. damnosum* au sud du Sahara est rendue difficile par l'existence de gîtes situés hors de la zone traitée et grâce auxquels les insectes adultes survivent à la saison sèche. Il n'empêche qu'il existe des projets de lutte intense susceptibles de mettre fin à la transmission de l'onchocercose, et que l'extension et la confluence des territoires traités accroît les chances d'une élimination définitive de cette affection.

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