Part II. - Techniques in use for the control or eradication of tsetse infestations

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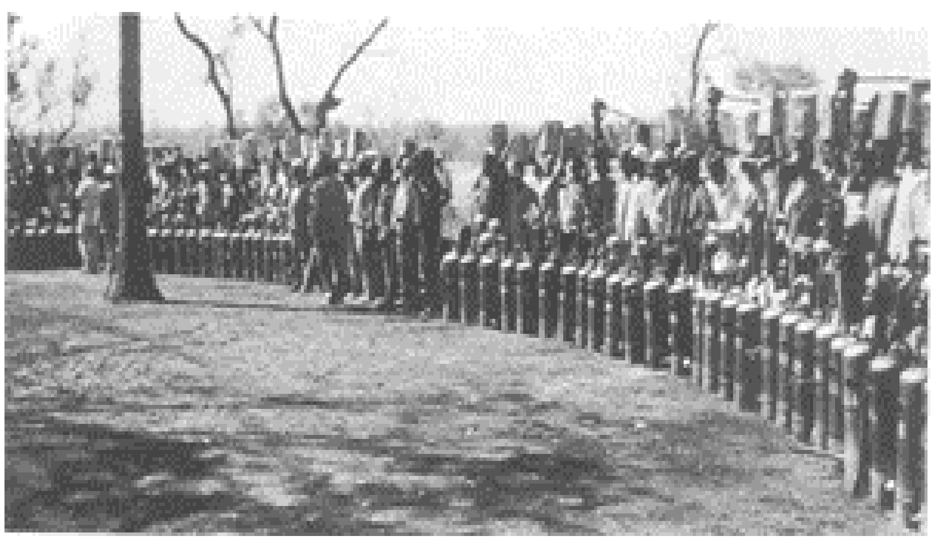
Part I of this article, in World Animal Review *No. 36, dealt in general terms with the problems of tsetse infestations and their effects on rural economies. This part discusses the general principles involved and the techniques in use in the control or eradication of tsetse infestation.*

Successful anti-tsetse activities have included methods such as hand-catching and trapping (Principe, *G. palpalis).* game eviction or destruction (Uganda, Zimbabwe, *G. morsitans, G. pallidipes),* various kinds of tree-clearing and the use of insecticides, or combinations of some of these techniques. Game eviction has been the cheapest method of suppressing savanna tsetse populations (Wooff, 1968), but is repugnant to most thinking people and is now difficult to administer. It is unlikely to succeed in West Africa where savanna tsetse populations thrive on very low game densities and it is not effective against the riverine species. In practical terms most of the anti-tsetse activity in the savanna zones has been by tree-clearing and insecticides either alone, or, more usually now, in combination.

Clearings

Because of the expense of clearing and the considerable maintenance commitment resulting from rapid regenerative growth, clearing activities in recent years have tended to be minimal, although, before modern insecticides became available, clearing operations against riverine tsetse were a major factor in the suppression of the sleeping sickness epidemics in Nigeria in the 1930s *(G. palpalis* and *G. tachinoides).* Though current anti-tsetse activity is mainly conducted through the use of insecticides, clearing still has a place in some sleeping sickness situations, as a means of protection on limited sectors of the perimeter of eradication projects (usually in combination with insecticides) and on the more intensive livestock projects.



Ground spray unit assembled for action in Nigeria. Such a unit can reclaim about 1 600 km^2 (1 000 sq. miles) of G. morsitans *and* G. tachinoides *infested land resource in one dry season operation.*

A variety of clearing objectives are involved, ranging from sheer clearing to selective methods tailored co the habitat and behaviour preferences of particular tsetse species and to climate. However, as with insecticides, selective methods become more difficult to devise and execute in the more humid environments because the habitat relationships of the flies become progressively more diffuse; the flies are more invasive and less dependent on particular components of the tree cover. Selective techniques have proved most successful in the more stressful Sudan and northern Guinea zones (Keay, 1953; Davies, 1964; MacLennan, 1967 and MacLennan and Na'Isa, 1971).

Sheer clearings have an important place on limited portions of the perimeter of insecticidal tsetse eradication areas, which are particularly vulnerable to reinvasion. Mainly because of expense it is not usually feasible now to think in terms of clearings more than 1.6 km (one mile) wide. These are usually supported by periodic insecticidal applications on each side or by buffer zones on the infested side from which infestations are periodically eliminated by insecticidal applications. Sheer clearings can also be important on less-extensive livestock projects where intensive fodder production or pasture improvement leads to the suppression or elimination of woody growth. If only an absolute minimum of shade trees remain, potential tsetse resting places under these can be periodically treated with persisting insecticides and this can ensure that tsetse levels are kept sufficiently low for treatment/prophylaxis to successfully control livestock trypanosomiasis. The economic feasibility of this situation is finely balanced and successful implementation is probably limited to localities of higher quality soil types and favourable rainfall. Furthermore, livestock have to be kept at a reasonable distance from any infested perimeter woodland/forest, or some kind of insecticidal buffer zone created, or else the adjacent area used for arable production rather than for grazing.

The actual technique of clearing that is appropriate depends very much on the circumstances. Selective objectives and the maintenance of the treated area have to be met by hand methods. In practice the performance of motorized saws has been disappointing. In some places large-area sheer clearings have been created by chain-dozing the woodland. The technique may be applicable to the savanna of West Africa though there appear to be no good examples of this. The big problem is again the control of regenerative or successional growth of woody species. Arboricides have performed disappointingly in the subhumid zone though possibly it is worth persevering to discover how to use these agents more effectively. The dozing, windrowing and root-ploughing of woodland or savanna followed by utilization for intensive forage production and intensive grazing possibly offers the best prospect of success provided rainfall and soil characteristics are suitable. The areas that can be handled, however, will be relatively small in relation to overall livestock production needs and the magnitude of tsetse infestation. Sheer barrier clearings are usually done by hand while in riparian associations regrowth is eliminated by piling cut branches on the stumps and eventually burning these, having protected them in the meantime from inadvertent or premature burn and theft of the cut material.

Ground spray of G. morsitans *dry season resting places in the Guinea vegetation zone*

Insecticides

Principles and methods of use. A variety of principles and methods is involved.

Since tsetse flies do not feed on vegetation, and wildlife food sources cannot be systematically dosed, lethal doses of insecticide are acquired by the flies either from the places where they rest, or the surrounding atmosphere while they are in flight or at rest. Methods may be classified according to the duration of lethality of the insecticide emission (transient, or non-residual, as opposed to persistent) and according to the method of dispensing the emission — for example, from the ground or by aerial application. In practice, persistent emissions are applied both by ground spray (usually by knapsack equipment, either hand-pumped, pressure-retaining sprayers or motorized mist-blowers) and by air spray (helicopter) while non-residual emissions are usually dispensed from fixed-wing aircraft or, occasionally, by helicopter. A wide variety of options in equipment and material is available, suited to different circumstances. The situation has been comprehensively reviewed in "Insecticides and application equipment for tsetse control" (FAO, 1976b).

Ground spraying. In recent practice ground spraying has been performed by the relatively precise placement of persisting deposits by teams of carefully supervised knapsack sprayers (Davies, 1964; MacLennan, 1967).

A single placement of insecticide on preferred tsetse resting places is used; the insecticide remains lethal to any adult tsetse that rests on it for a duration at least as long as the pupal period in the ground. An adequate safety margin is required to allow for the fact that in practice all resting places cannot be covered. The deposit is most effective when a lethal dose is picked up and adheres to the feet of the fly after a single contact, but lethal doses can also be acquired through an accumulation of sub-lethal contacts resulting from the daily movements of the flies to a variety of resting places.

Persistence for about eight weeks should be sufficient. However, in locations where reinfestation pressure is continuous *(control* situations) and in buffer zones protecting eradication areas, the duration of persistence should be as long as practicable (Lycklama a Nijeholt, 1965; Mac-Lennan, 1967).

To achieve these degrees of persistence relatively heavy dose rates are necessary but these are applied in a restricted manner developed from a detailed knowledge of the ecology of the target *Glossina* species in the particular environment. The insecticide must be placed where flies will contact it when resting, that is, in the preferred resting places, otherwise it is wasted. Thus blanket applications are ruled out mainly because of the difficulty in distributing such a weight of insecticide, its cost and the impact on non-target organisms.

Two degrees of limitation are practised: first, "discrimination" or dispersal only within tree cover of components known to be frequented by the flies, and secondly, "selection" or limitation within such localities to that stratum of the vegetation and places within it on which flies customarily perch. In certain circumstances the localities are quite specialized and easily recognized once the basic studies of resting behaviour have been carried out. The technology is based on ecological studies initiated by Nash in the early 1930s and continued since then (MacLennan, 1967; MacLennan and Cook, 1972; Scholtz, Spielberger and Ali, 1976). It is most effective when discrimination is of the order of 10-18 percent of the infested area. When the degree of discrimination is 10 percent, a dose rate of 60 g/ha overall in the sub-Sudan zone has achieved extermination, the local application rate being 600 g/ha. Overall dose rates increase with the proportion of the area included in the discriminative application.

The method depends for its success entirely on the acquisition of a sufficiently detailed knowledge of the resting preferences of the tsetse species involved in the particular environment of the project (MacLennan, 1967; MacLennan and Cook, 1972; Scholtz, Spielberger and Ali, 1976). Preferences vary very greatly from species to species and place to place (for example, that which is effective in the drier savannas does not work in the moister zones and that which is required for the elimination of savanna tsetse is very different to that required for riverine species).

Having decided upon the criteria for discrimination and selection and on the dosage rate, one usually applies the insecticide in linear swaths, but only to the vegetational features decided upon. The swath meanders with the vegetational feature and the width varies with local preferences and circumstances but may consist of four sprayers spaced at intervals of about 10 metres advancing in line and following the features decided upon

A single swath may follow both sides of minor drainages and vegetational interzones, particularly ecotones between savanna woodland and tree savanna, or one swath may be needed on each side of larger drainages. All drainages should be followed to their origins. For riparian forest ribbons the swath may be split between the outer and the stream-side margins of the forest and one swath may be needed for each bank. When dealing with savanna species a sharp look-out has to be kept for smaller habitat features such as small tree and thicket clumps associated with termitaria and footslope ecotones that are visible from the swath line and sprayers should be detached to deal with them. If substantial blocks of woodland are not penetrated even by minor drainages or tracks followed by spray groups, swaths should be sprayed at intervals of about 150 metres.

The groups spraying the swaths consist of labourers operating the pumps. Two men may be allocated to each pump and they alternate between actual spraying and carrying insecticide supplies for the man spraying. The groups are directed by trained field staff of the Control Assistant or Scout category, these in turn being supervised by Field Assistants and the whole operation in the field being under the direction of a Control Officer. The terminology varies from country to country but the chain of direction is similar in most places. The Control Officer is very dependent upon adequate maps on which the operation is planned and daily progress is recorded. Usually special maps have to be prepared for this purpose.

To gain access it is necessary to prepare in advance a network of rough motorable tracks and to cut access paths into denser vegetational features. The operation also requires an adequate number of lorries, pick-ups and tractors with trailers to transport personnel, insecticide and water.

The organizational or logistical commitments involved in the treatment of large areas are substantial but an operation unit of manageable size has been able to deal with 1 600 km^2 of *G. morsitarts* infestation in the sub-Sudan zone in Nigeria in one operational season. At that time Nigeria had four such units operational.

As a means of eradicating both *G. morsitans* and riverine tsetse infestations this approach has been highly successful in the Sudan and sub-Sudan vegetation zones but, although successful, it has proved more costly and more difficult to apply effectively in the northern Guinea zone. Much less is known of the relevant aspects of tsetse ecology in more humid locations and there are as yet no indications that similar approaches can be developed for large-area eradication in the southern Guinea or moister areas. Not only are relationships between the tsetse population and the vegetative environment much more diffuse and the tsetse more invasive (Molyneux, Baldry and Fairhurst, 1979) than in areas of greater climatic stress for *Glossina,* but the persistence performance of insecticide deposits is much lower in moister environments. This leads to the use of heavier deposits more generally applied and to sharply rising costs. Even between the Sudan and northern Guinea vegetation zones there exist very important differences in the resting behaviour of *G. morsitans* and in the persistence behaviour of insecticides.

Though further field study may reveal how this method could be applied to the southern Guinea zone and more humid locations for the elimination of tsetse populations, the outlook is not at present encouraging, though clearly the approach is appropriate in control rather than eradication.

The method is technically and financially efficient at levels of discrimination of 10 percent but if more than about 18 percent of the area has to be covered, costs escalate in proportion and there is greater concern about the environmental side-effects of the weight of insecticide being dispensed over wide areas. The annual rate of progress of an operational unit diminishes in proportion to any increase in the percentage of the area included in the discriminative spray.

Helicopter applications. Since the basis of the ground spray technique is the application of insecticide along linear swaths oriented to preferred tsetse habitats it is evident that a similar arrangement could probably be achieved by helicopters and that this would reduce the formidable organizational problems inseparable from large-area ground spray operations. Such a procedure would speed up the rate of reclamation of land resources from tsetse infestation. The concept has been made financially feasible through the development of ultra-low-volume (ulv) insecticide formulations and spray equipment suitable for use on helicopters, reducing very considerably the weight of the payload, which would be prohibitive if conventional insecticide formulations were used (Lee, 1977; Spielberger, Na'Isa and Ardurcahim, 1977).

Small helicopters are used (e.g., the Bell G4A) which follow closely the same localities as those visited by ground spray units. The helicopter flies at a ground speed of 32-40 km per hour (20-25 mph) and 24-32 km per hour (15-20 mph) over forest so that there is an adequate downdraught to achieve a dispersal of insecticide within and below the tree canopy. The machines fly as close as possible to the canopy (1-2 m) and operate from a large number of small temporary clearings made for landing and spaced to reduce non-spray ferrying time to the absolute minimum. The effective swath width in this case is about 20 metres.

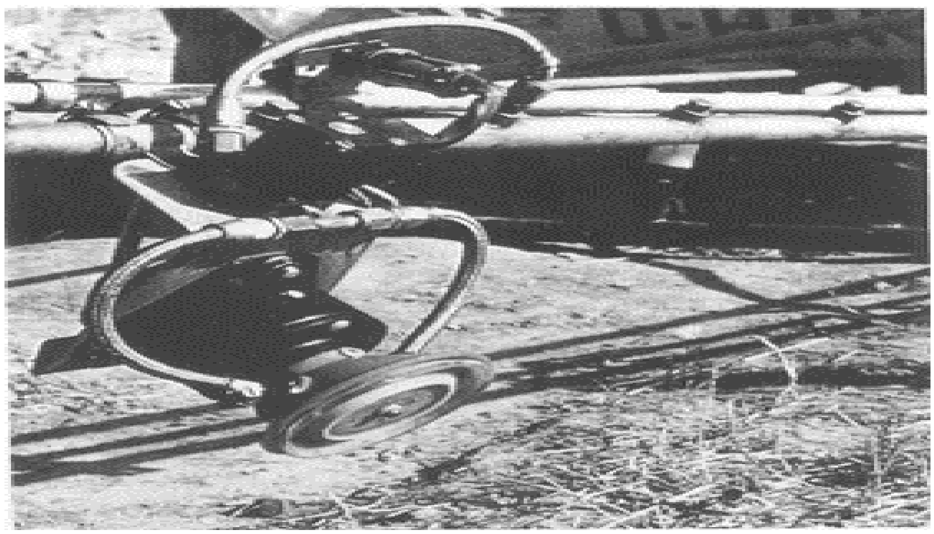
The emission equipment consists of six small, electrically operated and electronically controlled rotary disc atomizers mounted on a 3.2-m transverse boom under the rotor downdraught. Droplet size (determined by the rate of flow and viscosity of the insecticide and the rotation speed of the atomizers) is of crucial importance. Droplets must be sufficiently large to give a deposit with residual activity yet sufficiently numerous to give adequate coverage without being so light that they do not strike. Droplet size is also critical with regard to canopy penetration. Because of this, and the relatively small volumes of insecticide being dispensed, the metering of flow rates and atomizer speeds and the physical characteristics (viscosity, volatility) of the insecticide are of crucial significance to success. Adequate control is achieved through sophisticated electronic control systems and specially designed insecticide formulations. Ground speed becomes a crucial factor also in area insecticide dosage rates. Following any alteration to the several variables it is essential to monitor the droplet spectrum to determine that it conforms to specifications. For this purpose it is as well to seek independent specialist assistance at, or near, the commencement of the spray season.

Above *Motorized knapsack mistblowers in use against infestation in dense habitats*

Right *Livestock at Matyoro Lakes in northern Nigeria, formerly heavily infested* with G. morsitans, G. tachinoides *and* G. palpalis. *Freed of infestation by knapsack spraying of DDT and dieldrin*

The technique is very sensitive to meteorological conditions. After the earth is warmed by the sun a condition of turbulence develops in the lower air, which can carry small droplets upward and disperse them. Ideally a condition of temperature inversion should exist (ground temperatures lower than those at say 7.0 m). Because operations cannot be conducted in darkness, spray activity is effectively restricted to short periods around dawn and dusk. This can be extended briefly by increasing the insecticide flow rate from 4 to 5 litres per hectare, and the droplet sizes by reducing the atomizer rotation speeds. Atomizer speeds of 7 000 rpm will give the generally preferred droplet with volume median diameter of 150 (p.m, while reducing the rpm to 6 500 gives the larger droplet of 170 [pm needed when less favourable meteorological conditions develop. This increases droplet recovery at ground level by 25 percent. However, once turbulence becomes anything but minimal, or if wind speeds in excess of 7 m per second are encountered, spraying can become ineffective. It is emphasized that these figures relate to a particular insecticide formulation and that different criteria will apply to other formulations which will have different physical characteristics.

Left *Helicopter in action returning from spray sortie*



Below *One of six electronically controlled spinning-disc atomizers mounted on helicopter spray boom*

Organizational aspects of deploying and maintaining helicopters in the bush are formidable but, generally speaking, the requirements for labour and transport are much less than for ground spray of a similar area although the cost of helicopter hire more than offsets the saving on labour and transport. A two-machine spray unit can handle about 3 625 km^2 of infested area if the degree of discriminative spray is 10 percent, provided that the unit is smoothly serviced with supplies of insecticide, fuel and spare parts.

The helicopter spray unit requires the same degree of support in regard to pre- and post-spray tsetse surveys, map making and operational planning as does ground spraying and, in practice, it has usually been necessary to protect helicopter sprayed areas by ground spray methods at points where there are particular perimeter re-invasion threats.

In comparison to ground spray, higher local and overall dosages, are required since the element of selection within the swaths, discriminately sprayed, is minimal. As a result of this the impact on non-target organisms is substantially greater. Local dose rates in the Guinea zones are of the order of 800-1000 g/ha. If the degree of discrimination is 10 percent this results in overall dose rates of 80-100 g/ha of infested area. This will be proportionately higher at higher percentages of discriminate spray.

Both ground spray and helicopter applications become progressively less cost effective as the percentage of the area included in discriminative spray rises and, possibly at about 18 percent, is near the upper limit for both methods. At higher rates both cost and environmental aspects give cause for increasing concern. However, where *G. morsitans* advances are in progress or rapid action is required *to* reclaim an infested land resource there is no proven option, at present, other than helicopter spraying, which can be applied in the Guinea zones in cases where there is insufficient time to train, build up and equip the large organizations required for ground spraying.

Helicopter spray techniques have eliminated *G. morsitans, G. tachinoides* and *G. palpalis* infestation from substantial areas (Spielberger, Na'Isa and Ardurrahim, 1977). *G. morsitans* foci have sometimes persisted and have required follow-up applications that have usually proved successful. In practice the method has worked well for the extermination of riverine tsetse infestations in the northern Guinea, sub-Sudan and Sudan zones. Similar limitations on ground spraying exist in more humid areas.

Helicopter applications of non-persistent aerosols, though relatively costly, are feasible technically and could be considered appropriate to certain circumstances (van Wettere *et al.,* 1978).

Fixed-wing aircraft applications. Sequential emissions having a transient effect are blanketed at intervals in time and space over the whole of a project area (MacLennan, 1967). The flies acquire the lethal dose from the surrounding air, not from the surfaces on which they rest, as is the case when using deposits with residual activity. All, or nearly all, adults are eliminated following each application.

The applications have to be carefully timed to ensure that no flies that emerge from the ground following an application live long enough to deposit a viable puparium, and they must be repeated at this interval until the flies are beyond the end of the pupal period in the ground, by which time all puparia deposited before the spray cycles started have hatched. A knowledge of the timing of the reproductive cycle is, therefore, crucial for success. Both the period to first larval birth and the pupal period in the ground vary significantly according to prevailing temperature, becoming shorter at higher temperatures. Usually about five or six applications are required at intervals of about 10 to 19 days for a period of about *two* months. The mean periods can be calculated from average shade temperature to an accuracy of 10 percent (Phelps and Burrows, 1969) from tables compiled by Mulligan and Potts (Glasgow, 1970).

Small, light aircraft are used, of a kind that can take off fully loaded from bush landing-strips located as close as possible to the operational area.

Project areas are preferably rectangular in shape, with the aircraft flight lines oriented transversely to the prevailing wind. The aircraft flies at a speed of about 155 knots, as close as possible to the tree canopy — or about 7.0 m. As in helicopter spraying, a degree of skill and understanding is required of pilots that is of a much higher order than that required for ordinary agricultural crop spraying.

The project is covered progressively by parallel flight lines spaced at intervals of 300 m (sometimes less). The flight lines are controlled at each end from the ground, from cut lines made before the spraying commences and pegged off at the selected flight-line interval by personnel equipped with two-way radios and spotlamps. This personnel is responsible for calling a repeated flight on lines going wider than the acceptable minimum.

Very accurate navigational equipment is required to control both direction and distance. This operates either on the radar-doppler principle or from global, very low frequency radio beacons. If this equipment is sufficiently accurate with regard to direction and distance, a single-ended marking can be adopted, though some reservation has to be expressed regarding a complete lack of monitoring at one end of the flight lines. In some circumstances it is feasible to work from a single, central cut line, but again similar reservations apply.

Meteorological conditions are even more critical in aircraft applications than with helicopter spraying. Normally spraying is restricted to a short period of about one hour around dusk and dawn, while temperature inversion is still present, but, in flatter terrain, the general efficiency of the operation can be greatly increased by night flying, using a special beam-light fitted to the nose of the aircraft. The harmattan wind can be a problem, as in the case of helicopter spraying.

If a single aircraft only is available the operation becomes very vulnerable to any delays resulting from equipment failure. There is little scope for flexibility in timings and if there is slippage beyond the period to first larval birth the whole series of cycles has to start again from scratch.

There is a distinct limitation on flying over broken terrain. Since aircraft have to fly as close as possible to the tree canopy, the operation is best carried out in flatter types of country; it becomes hazardous in more broken country and quite impracticable in hilly country.

The aircraft usually flies at a speed of about 155 knots, emitting insecticide concentrate at the rate of 4-5 litres per minute (depending on the dosage required and the concentration of the active ingredient). The formulation is emitted from a single wind-driven rotary atomizer spinning at about 8 000-12 000 rpm (depending on the physical characteristics of the formulation) to obtain a droplet emission of 30 [pm volume median diameter.

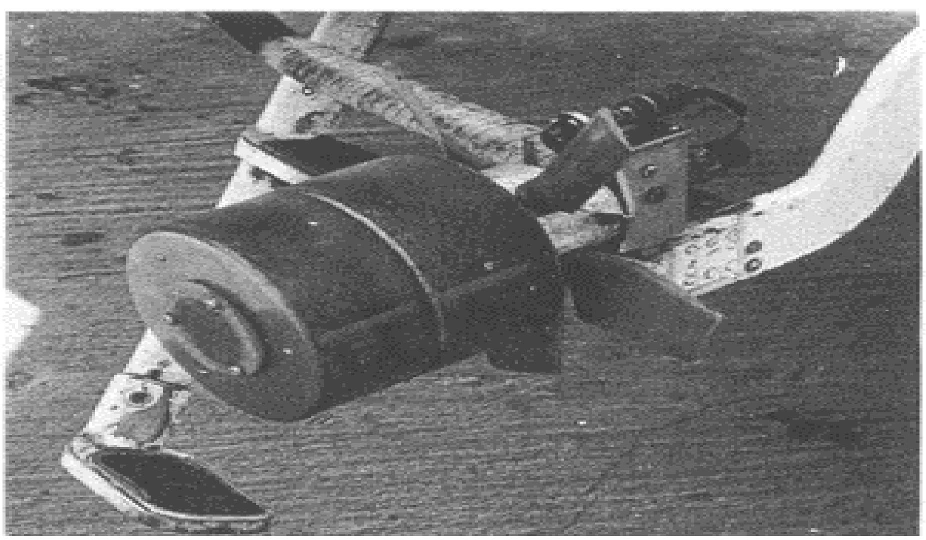
As in helicopter spraying the specifications are critical and careful monitoring of relevant aspects is essential to success. The technology of the emissions has been progressively developed since the early 1950s and is now highly refined, though there is still something to be learned regarding the effects of volatility and drift on optimum flightline intervals. A particularly important feature of the method is the very low dosage of insecticide used: it is of the order of 6-12 g/ha of project area for each spray cycle or 36-72 g/ha in total if six applications are made. The current use of aircraft, both fixed and rotary wing, for anti-tsetse work has recently been reviewed in detail by Lee (1977).

The result of aircraft applications on tsetse populations has been a rapid decline to zero, or something near it, in most instances followed, in some places, by a remarkably slow recovery, the population remaining reduced by about 90 percent for a period of at least three years. Unfortunately, there are no areas of a sufficiently large size that have remained completely free of infestation for long enough for it to be categorically stated that eradication of *G. morsitans* has been achieved by this technique, and there are certainly several locations where eradication has not been achieved. However, there is still scope for much further study on the entomological aspects of spraying by aircraft and a real prospect that further investigation of the survival and drift phenomena will ensure that this method regularly achieves extermination, although this is only possible under suitable conditions of terrain and climate. An additional impact could be produced by reducing the inter-spray cycle intervals to about 10 days, which, recent studies indicate, would ensure that no insemination takes place after the operation commences. There is no experience of the effectiveness of the technique over forest habitats and it would be wrong at this stage to dismiss the possibility of success. The point is of considerable importance since, at present, it is the only approach that can be utilized in these locations that is capable of striking and entering into the moister parts of the sub-humid zone.

However, regarding the current state of knowledge it must be said that the technique has been developed in environments differing in most respects markedly from the moister savannas, and has been used only against *G. morsitans centralis.* The as yet limited experience of the technique against *G. morsitans submorsitans* and *G. palpalis* of the sub-humid zone has been termed "encouraging" but it is still too early to know its actual potential for control or eradication of these species. However, since discriminatory techniques, which are known to achieve extermination, are reaching the limits of their capability in the more humid zone, it is essential to proceed with further development of the fixed-wing spraying technique.

Compounds and formulations. For ground spraying, only ddt and dieldrin have proved fully effective in the field over the years. The former is often used as a wettable powder containing 75 percent active ingredient mixed with water to give a suspension containing 2.5 to 3.75 percent of active ingredient. ddt has the merit of being exceedingly low in its toxicity for humans and it is possibly as a result of the prolonged biological activity at the locations to which it has been very selectively applied that tsetse eradication operations in the Sudan zone have proved so successful. Persistence of activity against *Glossina* can be demonstrated *in situ* for periods well in excess of 12 months (Lycklama a Nijeholt, 1965; and MacLennan, 1967). However, this degree of persistence is obtainable only if it is applied to bark in the dry stage in the Sudan zone and drier parts of the sub-humid zone. Performance falls off rapidly in moister environments where it may fail to achieve results even at much heavier dosages.

Above *Light aircraft being prepared for fixed aerosol spraying in Botswana*



Right *Wind-driven spinning atomizer. One only is required on wing trailing edge inboard of engine.*

In more-humid locations, ground spray operations have used dieldrin in emulsion form at strengths of 2-4 percent derived from 20-25 percent emulsion concentrate. The actual nature of the formulation of the concentrate has been shown to be of importance and, in some countries, a special 18-percent formulation is in use.

In denser habitats, such as swamp forest and thicket, it is sometimes necessary to use motorized knapsack mist-blowers in order to get an adequate dispersal of insecticide within the infested habitat (Koeman *et al.,* 1971). For this purpose a dieldrin emulsion is usually used at a final concentration of 2-4 percent active ingredient derived from 20-25 percent emulsion concentrate.

In helicopter spraying of residual deposits, special ulv formulations of diedrin (18 percent) and endosulphan (25 percent) are used, designed particularly to meet the requirements of anti-tsetse work. It is quite clear that failure will result unless criteria relating to droplet deposits (such as size, volatility, crystalline or surface availability on leaves or bark) are met.

For fixed-wing spraying of aerosols, endosulphan concentrates, sometimes diluted with a suitable solvent, are used at concentrations of 18-35 percent depending on the dosage rate required.

Over the course of the years all potential substitute compounds for these have been tried in the field. In spite of encouraging activity demonstrated in laboratory tests, none (with the exception of some of the new synthetic pyrethroids) has shown any capability of replacing ddt, dieldrin and endosulphan. Certainly, as regards biological effectiveness, there does at last seem to be some prospect of substituting the only compounds that have proved effective over the years with synthetic pyrethroids.

Direct environmental side-effects. These result from the effects of the insecticide emissions on organisms other than *Glossina* and can be immediate or longer term.

The restricted nature of ground spray means that the immediate impact is mainly restricted to organisms that occupy the places to which the insecticide is applied — which, ideally, may be 3-10 percent of the total project area. The fauna that occupies the same niche is affected, particularly insects and insectivores. Animals that are not insectivorous show little if any change and those, including insectivores, that frequent other niches, such as the canopy, are little affected. Some aquatic creatures do suffer an immediate impact. However, the majority of species in the area are not affected, and those which are mostly re-establish themselves from neighbouring unsprayed localities; the rate at which this happens depends on the invasive capability of the animal (FAO, 1977a; and Koeman *et al,* 1971). Two bird species in particular are slow to re-establish, namely the snowy crowned robinchat and the bluebreasted kingfisher. The latter is migratory and its permanent absence can be attributed as much to habitat alteration resulting from changed land use as to the direct effects of the pesticide.

Though it has been searched for, it has not proved possible in Nigeria to find any significant accumulation problem with ddt or dieldrin of a magnitude that would indicate that these compounds are having a significant, deleterious impact in those tsetse eradication areas where the desired result is achieved mainly through a single application of insecticide. It is different in control situations, where application may be required annually, but the number and extent of these are much more limited. It must also be borne in mind that side-effects will be greater in magnitude as the degree of restriction is relaxed, a point favouring fixed-wing application in more humid areas.

In the drier part of the sub-humid zone (the Matyoro Lakes in the sub-Sudan zone) ddt and dieldrin applied in 1961 as a restricted ground spray in a complex of woodland, forest and swamp forest eradicated *G. morsitans* and *G. palpalis* and possibly also *G. tachinoides* (MacLennan and Aitcheson, 1963). Following an investigation in 1970 of immediate and shortterm impacts in a neighbouring area after dieldrin applications, the 1961 area was revisited. All bird species noted to have been affected by the 1961 spray were present and fish were exceedingly numerous (and good to eat) in the small lakes of the system, which have only a very limited seasonal outflow.

The lack of an appreciable accumulation problem can be ascribed to the fact that, in eradication operations of this nature, the result is usually achieved by a single application and to chemical degradation resulting from high ultra-violet values and other features of the tropical environment

The immediate environmental side-effects of helicopter applications are substantially less specific since, although the discrimination is similar to that in ground spraying, the same degree of selection is not, and there is a significant deposition in canopy and aquatic habitats. The immediate impact on non-target organisms is more severe; some heavy mortalities result and some species are slower to reestablish (Koeman *et al.,* 1978). Longer-term accumulation problems are probably not very different to those following ground spraying. The direct impact is mitigated by having ground-sprayed blocks within the helicopter-sprayed area, or adjacent to it, by having unsprayed habitats adjacent to the area and by being careful not to include the whole of any particular type of habitat in the area sprayed (**FAO,** 1977a). Furthermore, the toxicity ranges of dieldrin and endosulphan differ: for example, bees are numerous in endosulphan areas 12 months after spraying while fish are less affected by dieldrin applications. Some reduction in the undesirable impact can be achieved by alternating blocks sprayed by either of these two compounds.

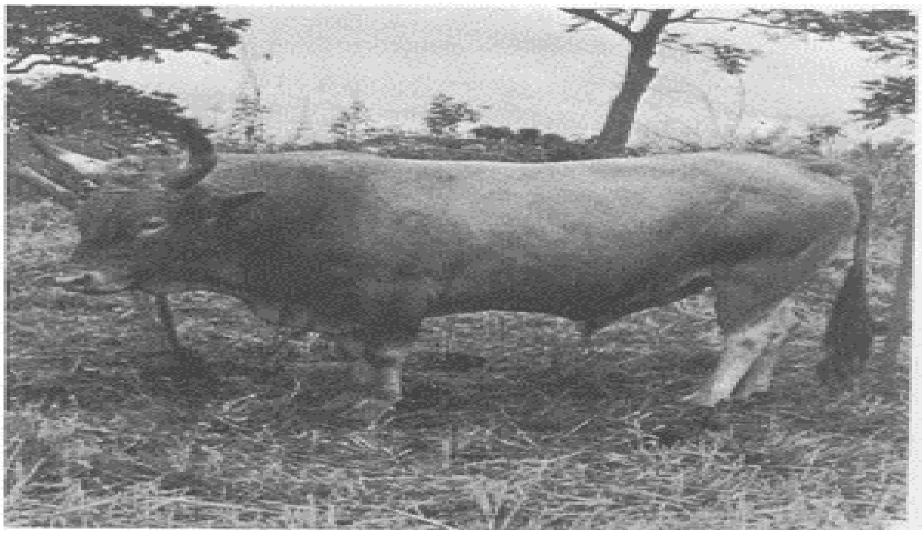
Fixed-wing applications of endosulphan have been studied over a period of three years in the Okavango delta in Botswana. No mortalities directly attributable to the applications have been observed in any species other than *Glossina,* Temporary accumulations of endosulphan, below levels of biological significance, have been observed (Russell-Smith, 1977 - personal communication; and Wood and Turner, 1975) in some species of fish and there is also some indication of transient behavioural responses in some species of fish and ants. The lack of side-effects is possibly not surprising when it is realized that dosages are of the order of 6-12 g/ha per application, much of which does not reach the ground. *Glossina* is particularly sensitive to this compound dispensed in this manner and it is again emphasized that there is no observable mortality of the other numerous Diptera present in sprayed areas, nor of any other animal studied so far.

Usually those engaging in anti-tsetse activity probably rank with the more responsible users of insecticides. Seldom, if ever, have they resorted to large-scale and repeated dispensations of the type that have caused trouble in the USA (Carson, 1961) and in Europe and they have shown no complacency about the continued use of ddt and dieldrin. An overall, balanced judgement is required (Provost, 1972). It is still necessary in some circumstances to use ddt for medical and agricultural reasons and it is not unusual in tropical agriculture to find application rates of 1 000 g/ha, sometimes repeated as many as five times in one growing season and repeated year after year, and to find that compounds such as ddt are a constituent of the applications. Application rates and usage practice in anti-tsetse work have been very different.

The basic objective of large-area anti-tsetse activity is often to facilitate land usage. If this objective is achieved, there is an unavoidable loss of wilderness habitats where these are not specifically conserved. The faunal changes that result from such a development are often of a much greater degree than those arising directly from the application of the insecticides and are of a more permanent nature.

Anti-tsetse techniques are still being improved and new ones developed and at last there is a real prospect of alternatives to the chlorinated hydrocarbons becoming available.

The most promising of the longeracting pyrethroids (decamethrin) has been found to be highly toxic to some fresh-water crustaceans but preliminary experiences show that these are again numerous after 12 months (Spielberger, 1978 - personal communication).



Above *West African N'Dama exhibiting high degree of tolerance to many West African strains of trypanosomes*

Right *West African Dwarf shorthorn (Muturu) cattle. These exhibit a high degree of tolerance to local strains of trypanosomes.*

Control and eradication objectives

There is a considerable diversity in the type of action against *Glossina* that will be appropriate under the different circumstances within the sub-humid zone. This will range from urgent *ad hoc* medical and /or veterinary measures (mainly diagnostic and therapeutic and sometimes augmented by vector control activity) required to contain the immediate consequences of a tsetse infestation affecting established livestock production or resulting in a sleeping sickness epidemic, to longer-term actions designed to eliminate infestation from very substantial areas so that planned development of the land resource can proceed without the serious complications that persisting tsetse infestations can cause. Though continental-scale eradication is not feasible, more local eliminations are feasible in appropriate circumstances and have been achieved in the past.

Anti-tsetse activities have two very different aspirations, namely control or local eradication.

In local *eradication,* a vector-free status is achieved and maintained throughout a large project area. The area is chosen so that tsetse elimination can proceed in a series of annual phases to embrace the entire local tsetse-belt or to take the project perimeter to locations that can be defended for an acceptable expenditure of funds and resources in relation to the area being protected. In *control,* activity is focal, related to specific sleeping sickness or livestock requirements and, since tsetse-free islands dispersed in a sea of infestation are relatively difficult to maintain and defend, a continuing, permanent commitment develops over a large area. This commitment involves vector and disease surveillance and countermeasures as appropriate. When disease episodes occur, the correct course of action is not always easy to formulate since it is often not readily determinable if the episode is due to a tsetse advance, to an occult infestation, drug resistance or maladministration of medicaments. The continuous deployment of scarce technical resources and the substantial supervision commitment are both difficult and expensive to execute and will continue permanently.

In the eradication project the supervisory commitment within the area becomes progressively less until it either takes place at increasing intervals or becomes oriented to the vulnerable sector of the perimeter, if this does not extend to the local limit of infestation. The technical expertise can then be deployed in extension of the fly-free area rather than becoming increasingly embroiled in the supervision of scattered control commitments and the elucidation of perplexing disease outbreaks.

However, the local eradication option can only be exercised where this is feasible in technical and financial terms. In this connection it has to be strongly emphasized that the possibility of formulating an eradication plan cannot even be perceived until a detailed knowledge of tsetse distribution has been acquired and a local field capability exists that is able to do this, collect basic information on habitat relationships and execute, or provide, field support for the anti-tsetse operation. In the absence of this field capability not only do possibilities of action remain obscured but, even if they should be known to exist, they cannot be executed in spite of the availability of financial and technical assistance that could be drawn upon.

It is essential to have an anti-tsetse technique that has been proved to achieve extermination of the particular species in that environment and this is usually developed from control activities or pilot projects. In the absence of a national field capability this experience also cannot be acquired nor can the organization be trained.

The facts of *Glossina* distribution and biology make possible the attainment of an eradication objective over very substantial infested areas of the savanna grazing resources where distribution is not homogeneous. The objective has been attained in several countries, and experience in Nigeria indicates that the objectives can be attained, though not so readily, in the drier parts of the sub-humid zone. The techniques have been developed after many years of field investigation and there is no reason to believe that, after similar expenditure of effort on investigation and technological development (materials, equipment, methods) eradication areas will not be progressively extended, though at present, as has been explained previously, existing, proven technologies are near the limits of their capabilities.

Where eradication objectives are unattainable at present, control situations have to be accepted. In terms of production, that which is feasible in the case of susceptible livestock by treatment or prophylaxis is determined by the degree of risk. As has been explained, higher-level production is usually not feasible except in areas of low risk.

Management

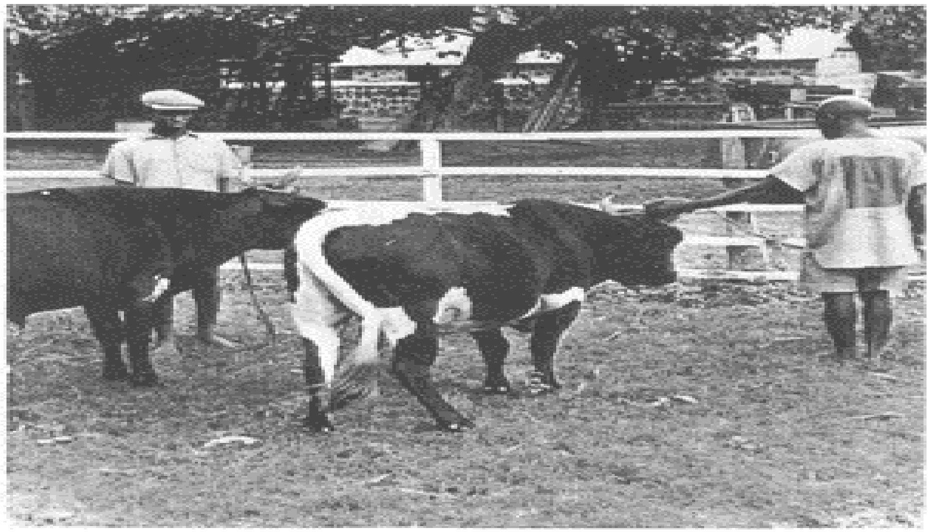
Treatment and prophylaxis. This is appropriate in conditions of low tsetse risk but, in areas of high risk, effective production cannot be ensured by such means unless accompanied by vector suppression (Finelle, 1976).

The difficulties arise from the fact that diagnostic techniques in the individual require a degree of simple laboratory support, that techniques are not completely reliable, and that they require the handling and bleeding of animals. The diagnosis of a trypanosomiasis problem is more readily made on a herd basis and the whole herd dealt with as appropriate.

Drug resistance can be an economically significant problem under static management systems dependent for success on a specific level of production. Repeated treatment in the presence of infestation, particularly if it is livestock-oriented, favours the development of a resistance problem. However, there is still some scope in situations of low tsetse risk, through the alternation of appropriate trypanocides, of reducing the impact of resistance even though, by now, crossresistance to several trypanocides is widespread. It seems that the unstable nature of the resistance phenomenon might soon lead to greater degrees of crossresistance between the currently available trypanocides. No new compounds are available to counter this, most of those available can be significantly toxic to one class of animal or another and there is no generally suitable trypanocide for *T. simiae* infections in pigs (even if there were one it would usually not be possible to administer it in time to save the lives of the animals).

It has been the usual experience that block treatment of entire groups of cattle at appropriate intervals gives better results than waiting for an individual positive diagnosis or until a percentage of the group becomes positive (this latter procedure should not be practised). Surveillance for infection of the entire group on a fixed management system is essential at regular intervals. The treatment of individual trypanosomiasis cases as they arise works in practice only in situations where tsetse risk is minimal, accurate diagnosis is swift and effective treatment follows promptly. The practical difficulty and cost of doing this, as, for example, on extended range, or on a ranch, or in servicing a dispersed group of smallholders with work-oxen, should not be underestimated, nor should the degree of technical expertise required to handle both animal health and the entomological aspects. Pastoral transhumants can accept greater risks and lower levels of production than is practicable under more static management systems. Properly controlled, closely supervised, mass curative treatment and strategically timed prophylaxis have done much to mitigate annual losses from trypanosomiasis and to increase the dry season utilization of infested areas. However, since drug resistance is of widespread occurrence, this practice has to be used with great care and also to ensure that treatment is not just encouraging owners to linger in high-risk areas. Thus, it can be appreciated that the careful supervision and management in the "control" situations require levels of expertise in the animal health and entomological aspects that are either not readily available or can only be deployed in relatively limited areas. Indeed, breakdowns resulting in serious disease outbreaks are not unusual even on very high level management projects. It is also evident that the needs of transhumants are not being fully met in a number of countries for a variety of reasons. These are some of the realities that have to be faced when deciding whether to proceed with the establishment of tsetse eradication areas where these are technically feasible or a control commitment where eradication is not feasible.

Though the difficulties involved have been emphasized, the trypanosomiasis problem can be adequately countered provided the risks have been correctly assessed as being of an acceptable degree and the animal health and entomological expertise is available to carry out the required countermeasures against the disease and, when necessary, against the vectors.



West African shorthorn in Ghana. These exhibit a high degree of tolerance to local strains of trypanosomes.

Tolerant and non-susceptible livestock. Stock that are exotic to the tsetse zone in origin are particularly susceptible to trypanosomiasis but, within the zone, there are breeds of cattle (Pagot, 1974), pigs, sheep and goats, horses and donkeys that exhibit degrees of tolerance of infection. As with treatments/prophylaxis the degree to which the phenomenon can be utilized to achieve effective production is related very significantly to the severity of the risk from *Glossina.* Constant exposure to high-risk situations and the intervention of "stress" periods (Stephen, 1966) can lead to clinical breakdown and sometimes death. Furthermore, it is usually the case that, until they have become infected and the immune defences activated, these animals are about as vulnerable to infection as any other animal (Roberts and Gray, 1973).

Trypanotolerant cattle, once adjusted to the local trypanosomes, produce meat effectively where fully susceptible animals would die. Daily weight increase and time to maturity of selected types under good management and negligible or unspecified degrees of tsetse risk can be impressive (Pagot, Coulomb and Petit, 1972; and Roberts and Gray, 1973). However, the working and milking capabilities of the cattle are usually low and animals reach optimum average slaughter weights at a size and time when the average zebu is near the rate of peak daily weight gain. There is still much to be learned about the production and reproductive capability of these animals (Stephen. 1966) under conditions of moderate and high tsetse risk, and there is no straight comparison available of the production per unit area from closed herds of zebu and tolerant breeds under comparable conditions in which *Glossina* is absent. All this information is essential to any assessment of the extent to, which the use of these animals can mitigate the trypanosomiasis problem or rather whether it would be better to pursue actions that make possible production from susceptible stock. There is much to be learned but though there is clearly an important potential for the appropriate use of tolerant animals under certain circumstances, it cannot be suggested that they provide a complete solution in situations of high trypanosomiasis risk. Their ability to cover ground is less than that of the zebu, though they appear to be much more resistant to streptothricosis. In any case these animals are in short supply.

There appear to be no livestock capable of producing meat that are not susceptible to tsetse-transmitted trypanosomiasis, other than poultry, fish and, in practice, rabbits.

Housing. Under zero-grazing systems susceptible livestock can be isolated from risk by keeping them in fly-proof accommodation when this is practical and economically feasible (as might be the case in pig production units and certain dairy units).

Methods under development

Sterile male release. The method is still under development and has the important advantage that it becomes more efficient, in the biological sense, at lower tsetse densities and has no detrimental direct side-effects on other organisms. However, efficient breeding colonies of each of the *Glossina* species to be eliminated have to be established and, though real progress is being made on colonization techniques, the individuals to be released are still costly to produce. Natural males have to be outnumbered 3:1 by sterile males, which can cost about US$ 1 to produce. Natural savanna tsetse populations have first to be reduced by non-persistent insecticide applications. In the sub-humid zone it is possible that the method may be applied more readily to the riverine species. However, regardless of the species, sterilized males have to be released regularly throughout the area for a period of several months, which, in some circumstances, could prove a major obstacle in areas of low human population density. This aspect, however, could prove no more difficult than the deployment of ground spray teams. A considerable logistic support, as in ground spraying, would, of course, be required.

Growth-regulating hormones. Compounds are available that have been shown to affect, for example, maturation of the puparium. Until such time as a powerful attractant is available for use on *Glossina* there exists an insurmountable problem in applying the compound.

At tract ants. There is as yet no powerful, long-range attractant though some promising advances in developing one are being made. The availability of such an agent would greatly improve the efficiency of survey and detection methods, would make possible the sterilization of natural populations rather than having to produce individuals from colonies and would make possible other channels of attack such as the use of hormones. In the present state of knowledge the availability of an effective attractant that could be used in the field would contribute more than anything else to our ability to deal effectively with the tsetse problem. ■

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