Natural Resources Institute

AERIAL SPRAYING RESEARCH AND DEVELOPMENT PROJECT

FINAL REPORT — Volume 1

Technical Report and Accounts

Regional Tsetse and Trypanosomiasis Control Programme
Malawi, Mozambique, Zambia and Zimbabwe

REGIONAL TSETSE AND TRYPANOSOMIASIS CONTROL PROGRAMME MALAWI, MOZAMBIQUE, ZAMBIA AND ZIMBABWE

AERIAL SPRAYING RESEARCH AND DEVELOPMENT PROJECT

FINAL REPORT – Volume 1

Technical Report and Accounts

by

R. Allsopp
(Team Leader)

Funded
by the

EUROPEAN ECONOMIC COMMUNITY
Accounting number 5100.35.94.269

In association with the

NATURAL RESOURCES INSTITUTE
Central Avenue
Chatham Maritime
Kent
United Kingdom

The Natural Resources Institute (NRI) is an internationally recognized centre of expertise on the natural resources sector in developing countries. It forms an integral part of the British Government's overseas aid programme. Its principal aim is to alleviate poverty and hardship in developing countries by increasing the productivity of their renewable natural resources. NRI's main fields of expertise are resource assessment and farming systems, integrated pest management, food science and crop utilization.

NRI carries out research and surveys; develops pilot-scale plant, machinery and processes; identifies, prepares, manages and executes projects; provides advice and training; and publishes scientific and development material.

Allsopp, R. (1991) *Aerial Spraying Research and Development Project. Final Report* – Volume 1. Chatham: Natural Resources Institute for the European Community.

No charge is made for single copies of this publication sent to governmental and educational establishments, research institutes and non-profit-making organizations working in countries eligible for British Government aid. Free copies cannot normally be addressed to individuals by name but only under their official titles.

Natural Resources Institute
ISBN 0-85954-320-X

Contents

Abbreviations

a.i.	active ingredient
ASRDP	Aerial Spraying Research and Development Project
COPR	Centre for Overseas Pest Research
DIMS	Doppler Inertial Mixed System
ECU	European Currency Units
GPS	Global Positioning System
MgO	magnesium oxide
NMD	number median diameter
NRI	Natural Resources Institute
ODA	Overseas Development Administration
ODNRI	Overseas Development Natural Resources Institute
RTTCP	Regional Tsetse and Trypanosomiasis Control Programme
SAT	sequential aerosol application technique
SEMG	Scientific and Environmental Monitoring Group
TANS	Tactical Air Navigation System
TAS	true air speed
TDRI	Tropical Development and Research Institute
TTCP	Tsetse and Trypanosomiasis Control Branch
VET	vehicle-mounted electric trap
VMD	volume median diameter

EXECUTIVE SUMMARY

TERMS OF REFERENCE

1. To define the optimum spray characteristics and navigational requirements for the eradication of tsetse *(Glossina* spp.) using aerosol insecticides applied mainly from fixed-wing aircraft.

2. To investigate how the fixed-wing technique can be modified to achieve tsetse eradication in rugged terrain.

3. To investigate other techniques which might possibly be used for terrain beyond the capabilities of fixed-wing aircraft.

4. To establish entomological parameters, particularly the rates of larval development of the relevant tsetse species at different temperatures in relation to the timing of spray cycles.

STATEMENT OF ACCOUNTS

Project expenditure and EC reimbursements May 1986 to August 1990

Period of claim	EC Payments		Project expenditure	
	to ASRDP Z$	to NRI UK£	in Zimbabwe Z$	in UK UK£
01.05.86–30.09.86	26215.70	51061.00	26215.70	20997.33
01.10.86–28.02.87	68124.30	20997.33 7700.00	68124.30	7700.00
Total 1986	**94340.00**	**79758.33**	**94340.00**	**28697.33**
Total 1987	**89969.19**	**13743.30**	**89969.19**	**64804.30**
01.01.88–31.03.88	3480.45		3480.45	
01.04.88–30.06.88	53695.35		53695.35	
01.07.88–30.09.88	83715.13	8871.48	3021.93	4148.30
01.10.88–13.12.88			80693.20	4723.18
04.12.88–31.12.88			8370.90	8791.67
Total 1988	**140890.93**	**8871.48**	**149261.83**	**17663.15**
01.01.89–30.06.89	20144.37	8900.02	11764.47	518.74
01.07.89–30.09.89	61069.53	13245.86	61069.53	
01.10.89–30.11.89	55201.46	2410.72	55210.46	12835.47
01.12.89–31.12.89	5089.63		5089.63	2410.72
Total 1989	**141504.99**	**24556.60**	**133134.09**	**15764.93**
01.01.90–28.02.90	14148.25	938.00	14148.25	938.00
01.03.90–15.08.90	51315.01	6210.51	51315.01	6210.51
01.03.90–15.08.90	3010.09	1429.57	3010.09	1429.57
Total 1990	**68473.35**	**8578.08**	**68473.35**	**8578.08**
GRAND TOTAL	Z$535178.46	£135507.79	Z$53578.46	£135507.79

CONCLUSIONS

Optimum spray characteristics

It is most important when measuring droplet parameters to use a standard sampling method. The MgO rotary sampler is cheap, available and easy to use. A handbook on sampling technique is in production and will be available shortly. Our results have been collected using a 330 rpm motor, 14 cm rotating arm and 0.635 cm MgO-coated microscope slide. The technique is also improved by including a fluorescent tracer in the insecticide and counting only marked droplets.

Operational spraying should always be preceded by calibration of the spray equipment.

The droplet size, expressed as the volume median diameter (VMD), should be between 20 and 30 microns (μm).

The lower size of this range is more effective but should not be achieved by increasing the atomizer cage speed (assuming a Micronair AU4000 or similar) for continuous use above 11 500 rpm in straight and level flight.

If calibration trials or operational sampling indicate a droplet VMD in excess of 40 μm, the spray gear should be readjusted or checks made for leaks.

Under normal circumstances, i.e. straight and level flying over flat terrain, the insecticide emission height will be determined by the tree canopy height. Pilots will normally stay within a few metres of the canopy but this is not critical and droplet deposition should not be severely affected even if the emission height were to double from, say, 20 to 40 m. When emission height exceeds 100 m, in rugged terrain etc., disruption of the insecticide's descent can be expected.

Increasing the flow rate while in flight over rugged terrain was not considered to be a practical option.

An operational flight interval (swathe width) of 250 m is a conservative standard for fixed-wing spraying and a 50% navigational error from the flight path would not severely disrupt insecticide coverage. In flat terrain the swathe could be increased to 330 m without risk but deviations from this wider swathe greater than about 25% might result in patchy distribution. In very rugged terrain, using helicopters preferably, 200 m swathes would be more appropriate.

Depending on the wind strength, insecticide droplets can be expected to drift 10-15 km downwind. If winds are confidently expected to be consistent in direction during a spraying operation, drift can be anticipated and incorporated into the control strategy. Regular monitoring is strongly advised.

Dosage rates for *G. morsitans*

Endosulfan

In flat and gently undulating country endosulfan should be applied at 22 g/ha for the first cycle, reducing to 15 g/ha for the second to fifth applications. In rugged terrain it would be prudent to increase the dosage rate to 25 g/ha, reducing to 20 g/ha.

Deltamethrin

The application rate should not be less than 0.25 g/ha for all cycles.

Dosage rates for *G. pallidipes*

Endosulfan

Under normal circumstances (flattish terrain, etc.) the first application rate should be 30 g/ha, reducing to 25 g/ha for the subsequent four cycles. This may need to be increased in more rugged terrain but should be confirmed by further trials.

Deltamethrin

No results to indicate suitable dosage for *G. pallidipes*.

Navigation

Accurate navigation is of paramount importance for effective and environmentally acceptable aerial spraying. Overdosing by respraying an area through navigational error is probably the most common cause of non-target mortality; notably among fish.

The Doppler-based system supported by an accurate heading and attitude reference platform (British Aerospace SGP 500) and true air speed indicator proved highly satisfactory and robust.

The navigation equipment must be capable of taking the aircraft accurately from the airfield to the starting point for spraying, keeping it on track for at least 100 km, placing the aircraft on a reciprocal path laterally displaced 200-250 m and repeating this for 2-3 h.

A 50% navigational error within the swathe is acceptable for 250 m flight intervals.

Savings could be made by reducing ground marker parties to one. A single marker party is useful for monitoring operational procedures but attempting to guide the aircraft between two or more ground stations simply negates the efficiency of the on-board avionics and is counterproductive. A beacon could be used for updating the navigation system or in case of navigational failure.

The Doppler/SGP 500 system has proven capabilities but the development of relatively cheap Global Positioning Systems (GPS) already promises a much cheaper and highly effective alternative. These would have to be investigated for use in any future operation.

'Omega'-based systems are not recommended.

Spraying in rugged terrain with fixed-wing aircraft

Aerial spraying from fixed-wing aircraft is feasible in rugged terrain provided the terrain is not too extreme. It is most suited to flat and undulating country where wide swathes (up to 330 m) can be used to good effect.

It can cope with more rugged, broken terrain, including river valleys and physical features, such as inselbergs, providing the emission height does not exceed 100 m for extended periods. Flight intervals of 200-250 m are recommended.

It cannot reliably provide an even distribution of insecticide at ground level and should not be used in extremely rugged terrain, mountains or along steep escarpments where the aircraft may have to maintain heights above the ground in excess of 100 m for long periods and perhaps entire sorties.

Spraying with helicopters in rugged terrain

The use of helicopters to control tsetse in very rugged terrain is a viable technique. The pilots are able to operate and, even in this most demanding environment, can navigate without sophisticated equipment providing the runs do not exceed about 20 km. Satellite navigation would greatly increase this capability.

During the 1988 trial, insecticide distribution and droplet sizes were acceptable although there was less drift. It would be prudent to reduce the swathe width to 200 m or less depending on the severity of the terrain for future operations.

The dosage of 24 g/ha was considered close to the critical minimum for the control of *G. pallidipes* in this terrain. A dosage of 28-30 g/ha was considered more appropriate. The technique was considered capable of eliminating tsetse, even the more difficult *G. pallidipes*, from very rugged country.

The charges for the trial were estimated at Z\$412/km^2 but this would have been less if the helicopter had been used in concert with a fixed-wing operation.

Larval development and the timing of aerial spraying cycles

The observed time between the emergence of female tsetse and the deposition of their first larva was 24 days at a daily average temperature of 20°C and 13 days at 27.7°C. This compares closely with the theoretical times calculated for routine aerial spraying operations, 19.19 days at 20°C and 12.76 days at 27.5°C.

It is therefore concluded that the period between sequential applications should continue to be one or two days shorter than the theoretical estimate of the first larval period from average daily temperatures.

Should future research indicate that the first larval period can in fact be shorter than anticipated the interspray period may need to be reduced. To date there is no firm evidence for this.

The *'pallidipes* problem'

Wind tunnel susceptibility studies indicated a minimum operational dosage rate for *G. pallidipes* of 25 g/ha. Theoretical modelling suggested a first application rate of 30 g/ha.

RECOMMENDATIONS

Research

The dosage rates recommended above for *G. pallidipes* should be confirmed by field trials perhaps by means of small-scale trials and marked tsetse.

Further trials to confirm the capability of helicopters to treat rugged terrain should be carried out.

Recent avionics developments, such as GPS, should be investigated for use in tsetse control.

The possibilities for improving target barriers to protect aerial spraying blocks from reinvasion should be investigated (work is being carried out in Zimbabwe).

A concerted effort should be made to determine if, under what conditions and how frequently female tsetse deposit their first larva in an uncharacteristically short time.

Operational procedures

These are largely summarized in Volume 2 of this report but a few points are highlighted here.

The high operational standards which have been set by the Regional Tsetse and Trypanosomiasis Control Programme should be maintained for future aerial spraying operations.

1. Contracts should only be awarded to contractors with the equipment and proven ability to meet these standards.
2. The awarding of contracts primarily on the basis of lowest cost should be avoided.
3. Eco-technical monitoring must be a feature of all future aerial spraying operations.

High priority should be given to reducing the cost of future aerial spraying operations.

1. Cheaper navigation aids should be investigated (GPS).
2. Track guidance from the ground should be minimized.
3. Flight intervals in flat terrain should be 330 m.
4. Where possible, contracts should be awarded for a series of operations rather than on an individual basis or a regional unit should be established.
5. The robust nature of the technique should be recognized so that unnecessary resprays are not enforced through navigational error or high flying.

INTRODUCTION

Aerial spraying for tsetse fly (*Glossina* spp.) control evolved from crop spraying and until recently it has relied upon techniques first tried, successfully, in the 1940s (Du Toit and Kluge, 1949). Commercial operations have tended to be awarded on the basis of single annual contracts and African contractors have thus found it difficult to find foreign currency, or justify major capital investment, to develop more appropriate techniques. Research has been undertaken by a relatively few organizations who saw potential in the system and who, generally, were aid funded: Tropical Pesticide Research Institute in Tanzania (Hocking *et al.*, 1953), GTZ in West Africa (Spielberger *et al.*, 1977) and the UK Overseas Development Administration's Natural Resources Institute (NRI; formerly ODNRI, TDRI and COPR) for example. NRI has been involved with aerial spraying for tsetse control in Botswana, Nigeria, Tanzania, Uganda, Zambia and Zimbabwe since the late 1960s (Allsopp, 1984). The high cost of aircraft hire has, however, restricted research to that which can utilize facilities provided through association with operational control activities.

Over the past 20 years several African Governments have turned to aerial spraying in an attempt to satisfy the rapidly growing demand for land and to compensate for the demise of large-scale ground spraying operations. As a result, contractors were more able to outlay funds for equipment specifically suited to tsetse control, rather than to adapt crop spraying equipment; indeed this became a necessity when night flying became standard procedure to exploit the more stable nocturnal meteorological conditions suitable for aerosol applications. Nevertheless, such equipment still tended to be acquired according to local availability and low cost, including the aircraft, which were not always usable for charter work after a season of spraying. Powerful 'landing lights' were introduced for operational night flying and fairly basic navigation equipment was employed to assist the ground-based track guidance systems which initially involved flags, fires or meteorological balloons.

Application equipment gradually improved as an expanding market developed. Most operators used Micronair equipment and Micronair (Aerial) Ltd produced a series of atomizers culminating in the AU 4000. They also improved the flow metering system and eventually designed a computerized flow controller and monitoring system. More recently, together with Agricair technicians in Zimbabwe, they have developed a system which automatically adjusts the insecticide flow rate according to changes in ground speed as estimated by the navigation system and true air speed (TAS) indicator; a major advance to compensate for variable terrain and changing wind speeds.

Various chemical manufacturers have been involved with the development of formulations specifically for aerial spraying. Shell produced an invert emulsion in the 1970s. Wellcome and Coopers (Zimbabwe) Ltd responded to a request for a formulation more suited to hilly terrain and Hoechst, which manufactures the market leading endosulfan emulsifiable concentrate, improved its product with a slightly less volatile 'T' formulation.

NRI was associated with most of these developments. It has a long history of insecticide testing, some of which was carried out as a reference centre for the World Health Organization, and defined the early droplet criteria for aerial spraying (Hadaway and Barlow, 1965). NRI application specialists have used a laminar flow wind tunnel to study aerosol behaviour under controlled conditions and have perfected a sophisticated system whereby 'mature aerosol droplets' of known size and number can be applied to tsetse to assess susceptibility (Johnstone *et al.*, 1989). They have used the opportunities in several African countries to test their laboratory findings under operational conditions and have often been involved with the field assessment of new or alternative insecticides for aerial spraying (Allsopp and Coutts, 1977; Allsopp and Hursey, 1986; Lee *et al.*, 1980). They designed a mathematical model which translates operational parameters and meteorology into estimates of tsetse mortality. Thus technical changes or new formulations can be assessed theoretically before being put into (more expensive) practice (Johnstone and Cooper, 1986).

AERIAL SPRAYING OPERATIONS IN ZIMBABWE 1982-86

1982

In 1982 Zimbabwe's Tsetse and Trypanosomiasis Control Branch (TTCB) began a series of aerial spraying operations in their Western Region. The TTCB's intention was to push the tsetse distribution limits in the Gokwe and Sebungwe areas of their Western Region back towards Lake Kariba. Then in subsequent years to work progressively north eastwards along the lakeshore in anticipation that the lake would provide a natural barrier to reinvasion.

The first operation was based at Chiwonde in the Chirisa Safari Area. An area of 2400 km^2 was treated by aerial spraying with a further 4000 km^2 by ground spraying around the aerial spraying perimeter to prevent reinvasion. The ground spraying was completed before the aerial spraying began.

Prior to the 1982 operation, aerial spraying for tsetse control had been confined to flat terrain typified by Botswana's Okavango Delta. The Chirisa Safari Area was mostly flat but had several prominent topographical features such as the Masikiri Escarpment which rises steeply for over 100 m, the steep-sided Dombwe Plateau and numerous outliers of escarpment grit such as Sinanjuli Hill. The prospect of eliminating tsetse from this area was daunting and in an attempt to re-treat selectively the more difficult terrain, a powerful and manoeuvrable Turbo Thrush was enlisted to complement the two Piper Aztecs which were to undertake the bulk of the spraying. In the event, the Aztecs were not reliable and most of the operation was carried out with a single aircraft with the Thrush standing in when required.

The area is drained by the Sengwa River and, on the western boundary close to the foothills of the Chizarira Escarpment, the Busi River. The Sengwa River meanders through relatively flat country fringed in parts by dense riverine woodland. The Busi River is in more rugged country with numerous densely wooded, steep-sided gorges.

The tsetse situation was continuously surveyed in the Gokwe and Sebungwe districts before the start of the Chiwonde operation mainly to monitor the extensive ground spraying operations in the area. 'Random' survey teams covered about 100 km^2 each month catching tsetse on bait oxen or acetone-baited screens. During March two random teams were deployed in the proposed aerial spraying area near Simchembu. They captured 779 *G. morsitans* and 383 *G. pallidipes* along the Sengwa and Busi Rivers in the north of what became the aerial spraying block. From April 1982 onwards an additional two 'fixed location' survey teams caught tsetse attracted to oxen along static transects. From July 1982 the random surveys were increased to seven and 12 white (Stanley) box traps baited with carbon dioxide, acetone and square black flags were deployed along the Sengwa River where both species occurred but where *G. pallidipes* was predominant. A vehicle-mounted electric trap (VET) was operated at Sipani Pan where (semi) permanent water attracted wildlife and where *G. morsitans* had survived numerous ground spraying treatments. The seven random surveys captured 1733 *G. morsitans* and 1198 *G. pallidipes* in July before the start of the aerial spraying. The box traps caught a total of 202 flies (mainly *G. pallidipes*), the fixed surveys caught 333 (mostly *G. pallidipes* from the Sengwa area) and the VET caught 80 (all *G. morsitans*) during the same period.

The aerial spraying commenced 27 July and ended 28 September. Endosulfan dosages were 25.0, 21.9, 15.6, 15.9 and 15.4 g/ha for the five applications.

Tsetse surveys continued and in November the random teams were increased to 16. No flies were caught in any part of the aerial spraying area by any method during that time. A few flies were caught on the edge and in the peripheral ground spraying. Most of these (30 *G. morsitans*) were caught in the vicinity of the Mtshezu River more than 20 km from the aerial spraying boundary. Two *G. pallidipes* were caught near the junction of the Sengwa and Busi Rivers in the north of the block, in the ground spraying area but close to the aerial spraying. A single fly (probably *G. morsitans*) was captured on the edge of the north eastern boundary, again in the ground spraying area but close to the aerial spraying.

At the time, the operation was considered an unqualified success and, despite antiquated aircraft operating one at a time, very difficult terrain and inadequate navigation equipment, it gave considerable hope that the TTCP now had a second and very effective string to its bow (Hursey and Allsopp, 1983).

Surveys continued in the Chirisa Area until October 1983. The Sengwa and Sipani survey areas remained fly free but a small number of *G. morsitans* were found close to a main road near the Burure River in the north of the aerial spraying block during March and April 1983. One *G. morsitans* was caught near the Sengwa Busi junction in May and a *G. pallidipes* was caught in the extreme northwest of the block at about the same time. This latter fly may have travelled from a population that by this time had been confirmed as having survived the ground spraying along the Mtchezu River. Additional ground spraying was carried out to treat known residual populations in the previous ground spraying areas but 'dissident' activity disrupted TTCP activities. When surveys eventually resumed, with a new generation of traps, the area was substantially reinfested.

1983

After the 1982 operation, the TTCB continued to roll back the fly distribution towards Lake Kariba with combined aerial and ground spraying operations between the Chizarira Escarpment and the lakeshore. The northern boundary of the 1982 treatment area, around Simchembu, where flies had survived the ground spraying, was retreated with an overlap of ground spraying.

The 1983 Binga operation over 2100 km2 was technically similar to that of the previous year but the terrain did not include massive features like the Masikiri Escarpment. It was, however, quite rugged with broken undulations increasing in severity towards the eastern boundary. The most difficult area was the steep-sided Ruziruhuru River valley which marked the eastern boundary.

The only other major difference was the use of deltamethrin (in diesoline solvent) for the first cycle only; it was applied at 0.25 g/ha. This was agreed between Wellcome and TTCB as a test of this alternative insecticide.

Two fixed fly rounds were deployed in the proposed block in May 1983. Their location was dictated by the presence of water for the oxen and was not 'entomologically' ideal. Their catches for June were 63 *G. morsitans* and 90 *G. pallidipes*, for July, 28 and 78 respectively. At about the same time two survey teams using screens and acetone were deployed along the Ruziruhuru River. Their catch for June was 1178 *G. morsitans* and 638 *G. pallidipes*. The number of random teams was increased to four just before the aerial spraying commenced. Stanley type box traps were positioned at each survey site and a VET was deployed to the area. Their July totals were 2385 *G. morsitans* and 1098 *G. pallidipes*.

Deltamethrin achieved a respectable reduction in fly numbers but was not 100% successful as a scattering of tsetse were captured in the post-cycle 1 surveys. These totalled 3 *G. morsitans* and 13 *G. pallidipes* for the block excluding the Ruziruhuru valley where a further 6 and 53 flies, respectively were captured. This failure to eliminate tsetse from the Ruziruhuru was not, however, limited to deltamethrin since a residual population remained along the river valley throughout the operation. Random survey teams were increased to nine after spraying ended and eradication did appear to have been achieved throughout the remainder of the aerial spraying block with the subsequent four applications of endosulfan. This result was supported by the dramatic reduction (elimination at three out of five cattle centres) in cattle trypanosomiasis (Hursey and Allsopp, 1984).

Surveys in and beyond the peripheral ground spraying east of the 1983 aerial operation recorded 4906 *G. morsitans* and 80 *G. pallidipes* in November. Reinvasion of the ground spraying area was inevitable and with a substantial population remaining along the Ruziruhru, the entire eastern boundary of the joint aerial and ground spraying operation was compromised. The situation was, however, contained by overlapping the 1984 combined spraying operation.

1984/85

The 1984 and 1985 operations based at Wadze progressively treated the lakeshore with aerially applied endosulfan and ground sprayed DDT. The results were similar to those of the previous years. The 1984 aerial spraying overlap eliminated tsetse from the along the Ruziruhuru River, suggesting that the failure in 1983 was an 'edge effect'. Scattered survivors were found after the first cycle of the 1984 operation (as with the single deltamethrin application in 1983) and a surviving, though reduced, population of *G. pallidipes* remained throughout the operation in the steep river valleys on the dip slope of the Umi Escarpment. The 1984 ground spraying was suspect and post-spray surveys revealed 'survivors' in both the aerial and ground sprayed areas.

Retreatment of the Umi Escarpment with aerial spraying in 1985 still did not achieve eradication, even though the recovery of insecticide droplets from valleys in the Escarpment was as high as in more exposed areas. It was concluded that the almost complete lack of (localized) night winds was responsible for the failure of droplets to impinge upon and kill tsetse. When it became apparent that aerial spraying was not going to eliminate flies from this small area (about 100 km^2) it was successfully ground sprayed. A few surviving *G. morsitans* were, surprisingly, captured during the aerial spraying operation and although most were close to the edge, four old *G. morsitans* were caught well inside the block between cycles 1 and 3. Post-spray surveys continued throughout 1985-86 and apart from a few flies in the north eastern ground spraying block the only flies caught in the entire treatment area were two *G. morsitans* on what had been the eastern boundary of the aerial and ground spraying.

The 1982 and 1985 series of operations was quite successful despite some obvious failings. Aerial spraying achieved some satisfactory results against both *G. morsitans* and *G. pallidipes*; it also gave some dubious results with the latter. It appeared capable of eliminating tsetse fly from quite rugged terrain but was inconsistent in this regard. Along the Ruziruhuru River it failed the first time but a second attempt eliminated both species of fly. On the Umi Escarpment it failed in both years in a very small area with localized meteorological conditions. Integration of ground spraying with aerial spraying was not entirely satisfactory and may have created (survival) problems which were attributed only to the aerial spraying, this being the technique on trial and under close scrutiny. On the Umi Escarpment, however, the use of ground spraying for localized 'mopping up' achieved the required result. Selective ground spraying, which treats 20% of a designated treatment area is designed for large blocks, not relatively narrow barriers. Its success depends upon tsetse moving to restricted late dry season concentration sites. It is almost inevitable that when used around aerial spraying boundaries there will be some movement into the aerial block between applications (Allsopp and Hursey, 1986).

FORMATION OF THE AERIAL SPRAYING RESEARCH AND DEVELOPMENT PROJECT

NRI entomologists, application specialists and meteorologists assisted the TTCB throughout the 1982-85 operations using the opportunity to assess the efficacy of the low-dosage, sequential aerosol application techniques (SAT), particularly in rugged terrain. The findings were applicable to other countries and did indeed contribute substantially to ODA's efforts in Somalia.

EC support for a Regional Tsetse and Trypanosomiasis Control Programme for Southern Africa (RTTCP) was confirmed in 1985. Aerial spraying was considered an essential component if the ultimate aim of eradication throughout the 320 000 km^2 common fly belt was to be a realistic objective. Funds were provided within the regional programme for NRI to accelerate their aerial spraying research and thus the Aerial Spraying Research and Development Programme (ASRDP) was formed.

OBJECTIVES

The ASRDP had a substantial amount of operational experience in Zimbabwe and other countries on which to build a research and development programme. In retrospect it is perhaps relevant that the SAT evolved in flattish, savanna type habitats characteristic of *G. morsitans* and the early successes in Botswana, Nigeria and Zambia were notably against this species. This was reflected in the dosage rates generally considered suitable and operational procedures which tended to be based on practical experience rather than scientific design, largely because of the cost of aircraft trials.

The TTCB recognized that hilly terrain would present problems when operational aerial spraying began in 1982. The dosage rates selected were consequently a compromise between this and their environmental concern. The first cycle dosage of 25 g/ha was relatively high but the latter applications were substantially reduced to about 16 g/ha. The TTCB achieved considerable success during this series of operations in the Western Region but small residual populations, particularly of *G. pallidipes*, became increasingly evident in rugged terrain.

The TTCB aimed to eliminate the annual recurrent costs of control by eradicating tsetse flies, thus even small residual populations were untenable. Also, since the SAT enabled several thousand kilometres to be treated in only a few weeks, the TTCB recognized that its policy of sampling 100% of the treated (ground sprayed) areas to search for survivors would become increasingly improbable thus 'eradication with confidence' was a primary target. The 1982-85 operations did eliminate tsetse from large areas, thus eradication seemed possible. The problems encountered in treating hilly ground and escarpments etc., with their inevitable meteorological vagaries did, however, need to be resolved. It became the primary focus of the ASRDP research programme to assess the possibility of eradicating tsetse from such terrain with SAT or to define the technique's limitations.

TERMS OF REFERENCE

The terms of reference stated in the contract between the Regional Authorizing Officer of the European Development Fund and NRI were as follows.

1. To define the optimum spray characteristics and navigational requirements for the eradication of tsetse (*Glossina* spp.) from terrain using aerosol insecticides applied mainly from fixed-wing aircraft.

2. To investigate how the fixed-wing technique can be modified to achieve tsetse eradication in rugged terrain.

3. To investigate other techniques which might possibly be used for terrain beyond the capabilities of fixed-wing aircraft.

4. To establish entomological parameters, particularly the rates of larval development of the relevant tsetse species at different temperatures in relation to the timing of spray cycles.

In addition, the contract called for the ASRDP to be represented at Regional Standing Committee meetings of the RTTCP and, latterly, to co-operate with the Scientific and Environmental Monitoring Group (SEMG) in the implementation of eco-technical monitoring.

As the project progressed it became increasingly apparent that the inability to eliminate *G. pallidipes* in a single operation was not entirely terrain related. The ASRDP eventually concentrated on this specific '*pallidipes* problem'.

WORK PROGRAMME

To fulfil these objectives the ASRDP carried out independent research activities but had to depend to a considerable extent on operational research associated with control. Development depended upon an interchange of information between the ASRDP, aerial spraying contractors and the contracting authorities. To this end the ASRDP took an active part in control operations, providing assistance and advice at the planning, operational and post-operational stages.

The annual work plans for 1986-88 were, therefore, designed to develop and refine the SAT so that it:

(a) achieves an even distribution of optimum sized droplets at the target site in a variety of topographical and meteorological situations through research to:

- define navigational requirements
- define the effects of emission height
- assess the effects of inaccurate flying
- refine flow metering and application procedures
- ensure that the most effective droplet size and number reach the target area

(b) achieves safe, effective, environmentally acceptable and economical aerial spraying by advising on:

- safety (aircraft and airstrip suitability, crew rostering, formation and night training)*
- effectiveness (timing based on larval development, surveys, suitability of weather conditions)
- environmental acceptability (loading procedures, dosages, navigational accuracy to avoid overspraying)
- economy (flight planning, swathe separation, tender and contract appraisal)*
- insecticides and formulations**

(c) can be supported by alternative techniques in areas which are not conducive to fixed-wing spraying, i.e. by investigating the use of helicopters for aerosol applications and by encouraging the development and integration of odour-baited, impregnated targets.

The project was extended from January 1989 to August 1990 to investigate the '*pallidipes* problem'.

ANNUAL BUDGETS

A work programme and cost estimate was prepared for each operational year. When approved by the RTTCP co-ordinator and the EC this formed the basis upon which provision was made for that year's running costs. Some of the expenditure was local, i.e. in Zimbabwe dollars, the rest was mainly in the UK in UK pounds sterling. After an initial advance from the EC to NRI, actual expenditure was reimbursed periodically on production of all original invoices, receipts or proof of payment. The annual allocations, subsequent expenditure and details of actual cost to the EC are summarized on page 11. The total cost of the project was £317,196 (ECU 452,626).

---

* Largely under the control of the contractor.

** In close collaboration with manufacturers.

Summary of provisions made for each annual work programme and actual expenditure

Start date	1.2.86	1.1.87	1.1.88	1.1.89	1.1.90
End date	31.1.87	31.12.87	31.12.88	31.12.89	30.6.90
Provision:					
Administration and running costs	33000	22000	21000	35100	20270
Navigation trial (and deltamethrin assessment)	51816	24700	5000		
Droplet studies	29960	21060	18300		
Larval development studies	18908	19300	14500	6000	
Meteorological studies	12100	7000	2000		
Physico-chemical monitoring		23000	28000		
Kakumbi Laboratory, Zambia		10000	49600		
Helicopter trial				15000	
Glossina pallidipes study				15500	10050
Consultancies and miscellaneous	15220	10900	17380	4250	2000
Bio-aeronautics student training	1500	2410	3540		
NRI (TDRI) administrative support	7700	6900	7966	3795	1620
Total allocation per year	170204	147240	167286	79695	33940
Actual expenditure in Z$	94340.02	89969.19	149261.83	133134.09	68473.35
Actual expenditure in UK£	28697.33	64804.30	17663.15	15746.93	8578.08
Total EC cost to NRI in UK£	67193.77	101520.53	66762.39	54263.84	27455.47
Total EC cost to NRI in ECU	95991.56	140195.78	95940.76	83553.53	36944.37

GRAND TOTAL EXPENDITURE 1986-90 £317196 (ECU 452626)

SUMMARY OF ASRDP RESEARCH ACTIVITIES AND RESULTS 1986-88

NAVIGATION STUDIES

A Decca Doppler-based navigation system was used for tsetse control in Zimbabwe for many years and proved to be a valuable component of any self-contained navigation system. For much of this time the 71B model was the sole navigational aid in the aircraft. As observers began to look more critically at operational performance it became increasingly obvious that accurate navigation was a prerequisite for tsetse eradication and the Doppler alone was not sufficient. Consequently the system was progressively improved; at first, by the contractor alone. In 1983 the addition of a Tactical Air Navigation (TANS) computer and TAS indicator provided increased capability to equate three-dimensional aircraft velocities with actual ground co-ordinates. The system was not simple to operate and with poor pilot continuity it did not achieve its full potential. The system lacked attitude reference information which was important for low level Doppler use and it was thought to be influenced by interference with the magnetic gyro compass. Deliberations between the Zimbabwean contractor and NRI identified the need for non-magnetic heading and attitude references to support the existing Doppler/TANS/TAS and with the formation of the ASRDP this became a priority. Discussions with avionics manufacturers revealed the existence of a single unit which would provide all of these requirements. The British Aerospace SGP 500 heading and attitude reference platform, though relatively old in avionics terms, was well tested military equipment that had proved dependable and accurate. It was also available on loan from British Aerospace.

Two years of testing with this integrated system and advice from a British Aerospace consultant showed the importance of correct installation, maintenance and pilot familiarity (ASRDP, 1988). This latter was largely achieved with the employment by the contractor of full time 'tsetse control' pilots.

Replicated trials using video recording techniques, together with technical advice and assistance from British Aerospace, have clearly shown that the Doppler Inertial Mixed System (DIMS), incorporating an SGP 500 twin gyro platform for heading and attitude information, is technically suited to the specific navigational demands of tsetse control by aerial spraying. This navigation system has the ability to take an aircraft to the spray location, keep it accurately on track for a period in excess of 2 h during which time it follows a grid of parallel flight paths 200 or 250 m apart and up to 80 km in length (ASRDP, 1987).

Operational capability and reliability was assessed during Zimbabwe's 1988 aerial spraying operation, which treated 2000 km^2 of the Zambezi Valley with deltamethrin. The operation used the DIMS/SGP 500 as the primary navigational aid and employed only a single ground marker party for track guidance support. In addition, a trial area of approximately 135 km^2 adjacent to the main block was treated without any ground track guidance support but with ground observers recording the navigational accuracy at known points within the block and collecting physico-chemical data.

There was considerable reluctance on the part of contracting authorities to depart from the use of two or three ground marker parties for track guidance. There was clearly, however, little point in using a highly sophisticated navigational system if the information given by it was over-ruled by ground teams who could only be as accurate as the maps and techniques they used to position themselves in the treatment area. Agreement to use a single central marker line was an advance and confirmation of the confidence gained by all those involved with aerial spraying for tsetse control. In the event, the system worked very well and although navigational errors did occur the percentage of accurate, dependable flying as recorded by both airborne and ground-based observers was impressively high. The most frequently observed error was in initial positioning over the entry point to the treatment area. Reliability was also generally good although Doppler antennae did have to be changed through malfunction and computer errors did occur.

Overall, the system confirmed its technical capability for this work and any minor doubts about reliability would easily be allayed by the provision of spare parts and back-up equipment. It would be unwise, for instance, to undertake an operation with a single DIMS unit, but one could operate without ground support if two aircraft were carrying DIMS and if known-location beacons were positioned in the treatment area for periodical updates.

In terms of cost, there would be savings if ground support were eliminated but a complete back-up Doppler/TANS/SGP system would cost in excess of £100,000. The latest generation of 'micro-chip' avionics may well be cheaper but even their manufacturer cannot confidently claim that they will be as accurate or reliable.

Having confirmed the capability and reliability of an appropriate navigation system, it remained to establish the accuracy of flying necessary to achieve adequate coverage of insecticide. We addressed that question in trials with a wider swathe width.

A small trial block (designated 2a) was used to assess navigational accuracy in 1988. It was adjacent to the main operational aerial spraying block close to the Zimbabwe – Mozambique border. This was treated in the usual way except that insecticide was applied over a swathe width of 330 m rather than 250 m.

Physico-chemical assessment of droplet distribution across this wider swathe was compared with 250 m swathes monitored by a Wellcome Research team close by in the main block and during the same night. Results are given in Table 1.

Table 1 Comparison of droplet recovery from 330 m and 250 m swathes

Parameter	Cycle	330 m swathe	250 m swathe
VMD	1	21	22
	2	20	
	3	32	35
	4	29	33
	1-4	24	31
Droplets/cm^2	1	1467	1150
	2	2329	
	3	171	130
	4	115	78
	1-4	1163	388
Vol (pl)/cm^2	1	3.5	3.9
	2	4.2	
	3	2.3	1.6
	4	0.5	1.0
	1-4	2.9	1.9

Droplet numbers and volumes tended to be lower from the 250 m swathes than the 330 m swathes, possibly because the Wellcome team left their samplers running for a shorter time than ASRDP. The results suggest that in the relatively flat terrain of block 2a and the adjacent main block, droplet distribution and insecticide recovery is not significantly reduced by widening the flight interval to 330 m.

In navigational terms, therefore, a 50% error in flight path separation would not severely disrupt the coverage over a 250 m swathe. It would reduce the amount deposited per unit area in the one swathe but in the normal course of events this would be compensated for by drift.

AEROSOL CHARACTERISTICS AND DROPLET BEHAVIOUR

Collaborative studies involving NRI and Wellcome Research Laboratories application specialists have greatly improved droplet monitoring techniques and these are now much more accurate and meaningful (Cooper *et al.*, 1987). The use of fluorescent tracers has eliminated spurious results caused by droplets of moisture and dust. Correction factors calculated from wind tunnel studies have also eliminated much of the sampling error which accompanied early comparative studies.

A VMD of 10-30 μm was suggested as suitable for 'drifting aerosols' by Hadaway and Barlow (1965) and 30 μm has indeed become the accepted standard when calibrating spray equipment using MgO-coated microscope slides. Improved sampling techniques have shown that operational VMDs are generally under 30 μm.

Aspects of droplet distribution, behaviour and insecticidal efficiency were studied during operational spraying or in small-scale trials. Drift, for instance, is an integral part of the aerosol technique. The smaller droplets stay airborne longer and are more likely to contact resting tsetse; they are also more likely to be affected by wind conditions and convection. The effect of flight interval or swathe width on droplet distribution was assessed and, with particular regard to rugged terrain, the effects of spraying height and variable flow rates were investigated.

DROPLET SIZE

An enormous amount of droplet data have been collected since 1982 during aerial spraying operations in Zimbabwe and other countries. Field observations and theoretical modelling suggested that an aerosol with a smaller droplet spectrum than the standard 30 μm VMD would actually result in a greater impaction of insecticide on tsetse flies. A preliminary trial to investigate this possibility was carried out in 1986 and did indeed indicate that a VMD of 21 μm would be more efficient than one of 27 μm (Johnstone *et al.,* 1987 a, 1987b).

A subsequent trial to compare the impaction of different sized droplets on live, wild tsetse flies was planned to follow the 1987 aerial spraying operation. For various logistical reasons the trial was delayed until early 1988, i.e. not the normal spraying season.

The trial was carried out at Rekomitjie over an area of 30 km^2 with two Cessna 401 spraying simultaneously. One aircraft applied a normal droplet spectrum and the second applied a smaller droplet size by increasing the atomizer cage speed from the standard 11 000-11 500 rpm to 14 500 rpm. The two aerosols were differentiated using fluorescent dyes and in order to enable the collection of live flies, a Thiodan blank formulation was sprayed. MgO-coated rotating slides were operated simultaneously for comparison.

The smaller droplets did not in fact result in a greater accumulation of insecticide on tsetse flies or on the MgO slides.

A more controllable physico-chemical investigation was also carried at an airstrip in Harare to quantify the effect of increasing cage speed. This again used Thiodan blank formulation.

By decreasing the AU 4000 blade angle by one notch (5°) cage speed increased from 11 500 to 13 500 rpm. By decreasing a further notch to the finest setting of 25° the speed increased to 14 500 rpm. Under operational conditions cage speeds can vary by as much as 1500 rpm either side of the expected 11 500 rpm. Even when increasing the cage speed to 14 500 rpm there was no significant decrease in droplet size (VMD) or increase in numbers/km^2 recovered.

The variation in droplet statistics derived from this increase in cage speed did not even compare with that observed between sites in normal operational spraying (ASRDP, 1988) as was found by sampling adjacent sites in a 3 x 3 sampling layout (Table 2).

Table 2 Comparison of deposits found on adjacent samplers positioned in a 3 x 3 square at four different sites

	Location in the square								
	NW	W	SW	N	M	S	NE	E	SE
Site 1									
VMD	29	35	29	–	32	31	32	30	32
no./cm^2	120	159	258	–	583	361	423	1078	816
pl/cm^2	0.96	2.52	2.41	–	7.37	4.17	5.50	12.10	8.3
ng/fly	0.04	0.25	0.58	–	0.89	0.96	0.17	1.30	1.9
Site 2									
VMD	–	25	26	26	28	21	22	19	
no./cm^2	–	220	1406	461	412	425	629	572	
pl/cm^2	–	1.30	3.50	1.50	1.20	0.90	1.10	1.20	–
ng/fly	–	0.15	0.35	0.15	0.05	0.08	0.09	0.20	
Site 3									
VMD	28	–	27	–	32	–	27	–	2
no./cm^2	283	–	1648	–	2708	–	1727	–	156
pl/cm^2	2.60	–	10.10	–	26.30	–	10.90	–	6.80
ng/fly	0.16	–	0.61	–	1.46	–	0.65	–	0.34
Site 4									
VMD	30	13	43	28	27	11	11	–	17
no./cm^2	58	521	167	558	113	969	1414	–	742
pl/cm^2	0.30	0.40	1.59	0.93	0.37	0.97	0.45	–	0.64
ng/fly	0.24	0.32	0.86	0.24	0.19	0.17	0.02	–	0.05

Overall mean VMD 26.2μm (SD 7.2), mean number of droplets/cm^2 728.8 (SD 630.0), mean ng/fly 0.45 (SD 0.48). No significant correlation between VMD and number of droplets/cm^2 (r −0.18).

Cage speeds in excess of 11 000 rpm are not recommended by the manufacturer for continuous use as this can lead to broken blades which in turn can, and in operational situations sometimes do, penetrate the fuselage. In addition to damaging the aircraft, this could result in the expense of an aborted sortie or environmental contamination.

Attempts to achieve such minor and inconsistent reductions in droplet size are not justifiable and unless different atomizers become available such attempt to reduce the droplet spectrum by this means is not recommended.

Other atomizers were tested in the hope that one would provide a smaller droplet spectrum which could then be field tested in a similar trial to that at Rekomitjie. A new Micron atomizer was tested at Charles Prince airport. Unfortunately the throughput of this small, wind-driven atomizer was very low and modifications had to be made even to enable a flow rate of 0.5 l/min to be achieved. This was the lowest rate achievable with the spray gear available to us. Normal operations involve flow rates of about 6-8 l/min. The overall flow rate could have been increased by fitting several units along a boom but only the single unit was available.

Despite these limitations the trial proceeded with one aircraft making 10 passes at a height of 15 m slightly upwind of a 210 m sampling layout. A fluorescent dye was used to mark the 'blank' insecticide formulation and droplets were collected on the standard MgO samplers. Results are summarized in Table 3.

Table 3 Droplet recovery from a Micron atomizer (values corrected for sampler collection efficiency)

Distance downwind (m)	VMD/NMD*	no./cm^2	vol/cm^2 (pl)	Mass of dye(ng) from fluorimetry
70	20/16	327	1.08	7.4
100	22/16	449	1.08	2.6
130	17/12	241	0.37	5.8
*160	21/16	158	0.50	3.2
190				3.4
210				2.0

*NMD = number median diameter

This atomizer produced smaller droplets although their numbers, even from 10 passes, were rather low. It did, however, show that possibilities exist to change application parameters. On a more practical level the atomizer was not sufficiently robust for continuous high speed use and the external rubber drive belt could well be affected by corrosive solvents.

A second type of miniature Micron atomizer was also tested and several of these were fitted onto a boom. These disintegrated on take-off and so were unsuitable for further assessment.

NRI continued this line of research in the laboratory and its Aerosol Technology Unit has designed and produced a prototype atomizer which produces a tighter, smaller droplet spectrum. This awaits an opportunity for field testing.

In spite of the rather negative field results we remain convinced that when taking factors, such as the effect of wind strength on impaction efficiency etc., into consideration the smaller droplets should still result in a greater volume of insecticide impacting on each tsetse fly. The current parameters will achieve the required entomological result but there is still scope for improvement. Thus, if for some reason dosages have to be increased (discussed later in relation to *G. pallidipes*) the possibility of limiting any corresponding environmental effects, by modifying the application parameters, should be given due consideration.

DRIFT

Small-scale aerial spraying trials in Botswana 1976 indicated that insecticide aerosols drifted several kilometres downwind in sufficient amounts to kill tsetse (Allsopp and Coutts, 1977). This was confirmed by Andrews *et al.* (1983) who collected chemical deposits of endosulfan 30 km downwind from the point of application.

Extensive drift is now accepted as occurring wherever the winds are of moderate strength and virtually all ASRDP droplet sampling exercises routinely placed samplers outside the treatment block. The 1987 control operation in Zimbabwe derived considerable benefit from the consistent easterly winds since the fly population outside the treatment area, along the western border, was greatly reduced to a depth of some 20 km. Tsetse surveys also recorded a population collapse in the centre of the treatment area apparently as a result of drift on katabatic winds during spraying along the escarpment bordering the treatment area. Droplet sampling in the location of these tsetse surveys did not reveal significant amounts of insecticide; at least not in droplet form and this raised the possibility of vapour toxicity. Laboratory studies carried out by NRI to investigate this possibility concluded that vapour toxicity is unlikely to contribute to the downwind mortality effects. Typical examples of insecticide drift are given in Tables 4 and 5 taken from the 1987 and 1988 spraying operations.

Table 4 Summary of insecticide drift (endosulfan) during aerial spraying in 1987

Location	VMD		No./cm^2		Estimated mass/fly(ng)
	observed	corrected	observed	corrected	
Cycle 1					
peg 26	20	15	6359	806	7.6
peg 28	29	25	2207	291	16.9
4 km downwind	20	15	550	77	1.2
8 km downwind	19	9	764	118	0.2
16 km downwind	16	13	195	32	0.4
Cycle 2					
peg 26	26	17	2881	1065	40.0
2.5 km downwind	21	18	67	15	0.5
26.5 km downwind			0	0	0

From Table 4 it is clear that the smaller droplets travelled a considerable distance but at 16 km their numbers were greatly reduced. At 26.5 km, they were undetectable with the equipment used.

Table 5 Summary of insecticide (deltamethrin) drift from cycles 1 to 4 during the 1988 aerial spraying operation in the Zambezi Valley

Distance drifted (km)	Mean VMD	Mean no./cm^2	Mean vol/cm^2 (pl)	Mean ng/fly
1-5	17	537	0.76	0.02
6-10	13	418	0.60	0.02
11-15	21	347	0.70	0.05
16-20	28	4	0.03	<0.01

Furthest distance drift recorded = 25 km

EFFECTS OF EMISSION HEIGHT

The height at which aircraft release insecticide during aerial spraying obviously affects the distribution at the target site. Droplets were recovered from surprisingly great heights, i.e. in excess of 500 m along the Zambezi Escarpment, but at these extreme heights droplet distribution was patchy. There is, however, a considerable amount of latitude in the heights at which insecticide can be released without seriously affecting the volume and distribution of insecticide at ground level.

'Normal' flying height in flat terrain is governed by the vegetation and the pilots fly just above the woodland canopy by day or night. To illustrate typical flying heights, records were taken from the radar altimeter (in feet) during the 1986 operation (Table 6).

Each height in Table 7 is averaged over a 50 km run from the number of altimeter recordings shown. A pilot with minimal low level flying experience maintained a similar height to that of the chief pilot. Both were marginally higher when flying into the sun but they were routinely able to stay within a few metres of the canopy which was about 50-55 ft (15-17 m) high.

The helicopter trial in 1988 was an example of a typical, though not extremely high, spraying during which spraying heights were recorded. The helicopter was fitted with a radar altimeter which provided the opportunity to estimate spraying heights in certain locations. The pilot and co-pilot were too preoccupied during spraying to take continuous altimeter readings but some records were kept and it was possible to obtain 'spot heights' in places where they were visible from the ground and where they only had to pass information over the radio.

Table 6 Samples of operational spraying heights (in feet as on the altimeter) during 1986 aerial spraying operation over flat terrain during late afternoon daylight

Date	Height (ft)	SD	No. of records	Comments
12.9.86				
	Inexperienced pilot			
	71.36	34.55	70	flying into sun
	61.60	20.50	71	flying away from sun
	69.20	22.20	39	etc.
	65.40	15.60	24	
	69.40	19.10	16	
	64.30	18.30	37	
mean	66.88			
	Chief pilot			
25.8.86	59.00	9.97	13	flying away from sun
	63.90	10.30	33	flying into sun
	55.89	13.30	28	etc.
	63.90	14.98	33	
	57.42	11.54	31	
	61.67	16.06	24	
	52.61	5.41	23	
	60.50	10.56	20	
	63.33	12.38	21	
	62.00	12.81	20	
	59.13	11.24	23	
	66.67	13.97	15	
mean	60.50			
overall mean	62.62			

Thus spraying northwards on run 8 they could be seen climbing out of a valley and they reported heights above the ground as 100, 120 and 100 ft. As they returned and passed over peg 9, which was on a ridge, they were 200 ft above the marker vehicle. At peg 10 they were again quite high at 150 ft, but on both pegs 9 and 10 the insecticide could almost immediately be smelt at ground level.

Droplet samplers were placed near pegs 8, 8.5, 9, 9.5 and 10 to assess droplet distribution across swathes in that area and the results are summarized in Table 7.

Table 7 Summary of droplet statistics for cycle 2, in block 1 of the 1988 helicopter trial, over rugged terrain (actual data and data corrected for wind speed given)

Sampler location	Total droplets counted/ transect	Droplets/ cm²		VMD (μm)		NMD (μm)	
		u	c	u	c	u	c
peg 8	19.0	275	1000	34	30	23	16
peg 8.5	3.6	52	196	39	33	22	16
peg 9	4.3	62	285	35	28	22	13
peg 9.5	9.0	165	967	38	29	19	13
peg 10	39.3	565	4168	42	28	17	12

u = uncorrected c = corrected

The above examples were selected to illustrate normal spraying heights, typical increases in rugged terrain and the fact that such increases do not severely affect the ground level recovery of insecticide. Where normal operational spraying procedures are observed over flat or undulating terrain emission heights, even in excess of 45 m (150 ft), should not result in poor droplet distribution.

When the spraying height increases substantially above 45 m, i.e. to 100 m and more, localized meteorological conditions have a more pronounced effect and the descent of the aerosol can be severely disrupted. In a flat area of the 1987 treatment block the corrected number of droplets/cm² collected on MgO samplers varied from 180 to 480 (mean 271). Extrapolating from these data, the amount of insecticide available to strike an individual tsetse varied from 3.6 to 12.7 ng. During the same operation, using identical procedures but spraying along the Zambesi Escarpment an array of samplers recorded droplet numbers from 4 to 620/cm² extrapolating to 0.44 to 57.8 ng/fly. Some areas of the extremely hilly escarpment were therefore overdosed and others underdosed.

Extremely rugged terrain along the Zambezi Escarpment was again included in the 1988 operation and at times the aircraft sprayed from heights in excess of 800 ft (240 m) above the sampling positions. The average droplet recovery is given in Table 8.

Table 8 Droplet recovery from rugged terrain averaged over five cycles during the 1988 aerial spraying operation

VMD (μm)	22.00
No./cm²	126.00
Vol (pl) /cm²	0.50
Predicted ng/fly	0.05

The predicted mass per fly did not exceed 0.08 ng at any sampling site. Since most of the solvent evaporates within metres of leaving the atomizer the VMDs were understandably of the same order as those recorded from less extreme terrain, but deposits measured by number and volume/cm² were lower.

VARIABLE FLOW RATE

Knowing that surprisingly high recovery rates are sometimes recorded in hilly terrain but distribution of insecticide is inconsistent, it was thought possible that in rugged terrain the amount of insecticide reaching the target area at ground level might be increased by increasing the flow rate.

In practice, this is not easy once the aircraft is airborne. Even the small trial in 1988 to investigate droplet distribution over an increased swathe width proved more difficult and time consuming than anticipated. In this case the entire block was treated with the increased flow rate and the rates were set before take-off by opening a main gate valve in the spray gear and recalibrating the flow controller. After the trial the spray gear had to be reset for normal spraying; this took time to carry out and then time for the pilot or co-pilot to adjust the flow controller setting during the following sortie.

The concept of variable flow rates in rugged terrain was based upon in-flight changes to accommodate variations in emission heights. This is similar in concept to the automatic change in flow rate already achieved by the flow controller to accommodate changes in estimated ground speed. This would require a major modification to the equipment but is practically possible.

To test the feasibility, fluorescent dyes were again used to differentiate insecticide applied from different aircraft. One aircraft in the formation increased the flow rate by 50% while the other remained on normal settings. A single sortie in a particularly difficult area of the Zambezi Escarpment was treated in this way.

Droplets were recovered from aircraft employing both normal and increased flow rates but there was no indication that underdosing through inconsistent distribution of insecticide could be overcome by increasing the amount of insecticide applied.

METEOROLOGY

Extensive studies with a variety of sophisticated recording equipment were designed to quantify the meteorological parameters which are most likely to affect droplet fall-out and drift. An acoustic sounder was used to create a graphic description of stratified inversion layers which build up at sundown and decay from the ground upwards to a height in excess of 500 m as convection follows sunrise. Below the lower limit of the acoustic sounder a 22 m telescopic mast was used to measure temperature, wind speeds and directions to canopy, i.e. normal spraying, height. Wind speeds were consistently higher and sometimes in a different direction at the emission height than at 1 m above the ground where meteorological monitoring normally takes place. Portable recording stations are now a routine feature of aerial spraying operations for the correction of physico-chemical data and to help explain any discrepancies which might occur in the expected entomological result.

Meteorological information collected along the Zambesi Escarpment gave rise to a significant change in strategy in 1987 when strong early morning south-southeast katabatic winds contra-indicated spraying at this time and effectively halved the available daylight spraying time in the difficult and hazardous terrain. After the first cycle the escarpment was only treated between 16:30 and dusk, when there was an inversion but no excessive winds. To complete spraying of the allotted area in the time available the formation was increased from two to four. In spite of the difficulties and the uneven insecticide distribution, the result was encouraging.

Meteorological recorders placed in the steep-sided river valleys of the Umi Escarpment confirmed the lack of (recordable) wind and helped explain the survival of *G. pallidipes* in this area, despite the recovery of high droplet numbers (Allsopp and Hursey, 1986). Subsequent theoretical work confirmed the relationship between ultra-low winds and survival which helped explain the survival of *G. pallidipes* in an area of flat, relatively 'easy' terrain in 1987. Consistent easterlies in 1987 caused drift and substantial tsetse reductions west of the treatment area, factors which greatly affected the strategy for 1988 in a similar area of the Zambezi Valley.

LARVAL DEVELOPMENT STUDY

This associated project was co-funded by the Overseas Development Administration (ODA) (special research fellowship R3970) and the EC which provided additional equipment. The project appeared in the ASRDP annual budgets for 1986 and 1987 but no costs were charged until mid-1988 when it eventually become operational. Based on an island on the Zambian side of Lake Kariba, it proved difficult to supervise at such a distance in a remote area with no communication link. The Tsetse Research Laboratory (TRL), Bristol agreed to provide a short-term consultant and laboratory support. Dr Langley made several visits which proved most productive.

The objective was to investigate the relationship between larval development and temperature. This is currently used to determine the optimum period between cycles to ensure that newly emerged female adults do not have time to deposit larvae. The first larval period (FLP), which is applied to all tsetse species, and thus the interspray period (FLP-2 days) is determined from the relationship:

$$\text{first larval period (days)} = \frac{1}{0.0661 + 0.0035(t-24)}$$

(t = mean daily temperature °C)

The research was based on mark/recapture, ovarian dissection and subsequent correlation of inter-uterine larval development with ambient temperatures. Wild caught *G. pallidipes* pupae were supplied when available from the Rekomitjie Research Station in Zimbabwe and laboratory-reared flies were provided by TRL.

A total of 3431 flies were released on the island (Table 9) and 199 were recaptured. Additional data on *G. morsitans* were provided from TRL where flies were kept at constant temperatures ranging from 20 to 32.5°C.

Table 9 Release and recapture of marked tsetse on Gwena Island 1989/90

Month	*G. morsitans*		*G. pallidipes*	
	male	female	male	female
August	24	22	218	75
September	470	431	493	579
October	16	10	195	228
November	0	0	43	18
December	0	0	0	0
January	137	135	0	0
February	178	222	0	0
March	87	20	0	0
Totals released	912	840	779	900
Recaptures	68	47	21	45

The period between female emergence and the observed first larviposition was 24 days at 20°C and 13 days at 27.7°C. The theoretical rates at 20 and 27.5°C are 19.19 and 12.76 days, respectively. These results show that the observed rate of first larval development is sufficiently close to that predicted from the formula above so this should continue to be used for estimating the time between applications.

SUMMARY OF RESEARCH ACTIVITIES AND RESULTS 1989-90

HELICOPTER TRIAL

Location: Shamrocke Mine, Zimbabwe
Block size: 126 Km

Operational statistics: aircraft – Bell 206 Jet Ranger II

Maximum speed – 165 kph (descending)
Minimum speed – 80 kph (climbing)
Estimated average – 135 kph
Atomizer – Micronair AU4000 x 2 (blades 12 cm blade angle 25°)
Swathe – 250 m
Insecticide – endosulfan 30% ec (Hoechst 'T')
Tracer – Hostasol yellow 3G

	cycle 1	2	3	4
dosage planned (g/ha)	24.00	24.00	24.00	20.00
dosage achieved	23.94	24.45	25.44	20.46
flow rate (l/min)	4.5	4.5	4.5	3.75
application (l/km^2)	8.0	8.0	8.0	6.66

The insecticide used was endosulfan 30% ec (Thiodan 'T' from Hoechst) left over from previous operations conducted by the TTCB. The concentration was checked by Hoechst and confirmed as 30.4%. It was necessary to use 30% throughout the trial to enable the helicopter to lift the required volume for the intended treatment area whilst keeping the number of sorties to a minimum. Hostasol yellow 3G was used to lace the insecticide so that insecticide droplets could be clearly distinguished from other artefacts during droplet monitoring. As no fluorimetry was planned, the concentration of dye was roughly estimated at 0.05%.

Preliminary trials indicated that with a belly tank and twin atomizers fitted, plus a co-pilot, the maximum load of insecticide should not exceed 300 l. With the expected difficulty of climbing away from the Shamrocke Mine loading area in the late afternoon a maximum safe load of 280 l was agreed. Assuming a retention of 20 l in the spray gear system the usable load would be 260 l.

Assuming approximately one hour's spraying time in the late evening and early morning and an average speed of 135 kph, each sortie could treat a maximum block of 33.75 km^2. At a dosage rate of 24 g/ha this would slightly exceed the safe load so a treatment area of 31.5 km^2/sortie was agreed.

With the time available, four such blocks could be treated, giving a total block size of 126 km^2 for each of four applications.

The helicopter was not fitted with sophisticated navigation equipment such as Doppler or the SGP 500. Navigation was therefore jointly undertaken by the pilot and co-pilot using maps and following recognizable features of terrain, roads and rivers etc. Preliminary familiarization surveys within the block were undertaken. As an additional aid, a marker line was pegged out at 250 m intervals along one road which roughly bisects the block and from where a marker party with flares could give some directional assistance. The runs in blocks 1, 3 and 4 were 4.5 km long; those in block 2 were 7 km long, thus the aircraft was never far from a marker update.

The block varied in altitude from 507 m in the Angwa river bed to a high point of 987 m, with several distinct peaks above 900 m. Generally, the terrain varied between about 600 and 900 m (a variation recorded on the radar altimeter of about 950 ft).

During preliminary trials the pilot reported average speeds between 135 and 165 kph and atomizer cage speed approximately 12 000 rpm. Droplets recovered on MgO slides were of an acceptable size and density (27-28 μm corrected VMD and 1000-2000 corrected drops/cm^2).

Three meteorological stations were positioned within the treatment area — two in river valleys and one on an exposed ridge. The westerly component was the most consistent of the early morning and late evening winds. Some variation from south westerly to northerly was recorded with occasional north easterlies recorded in the late evenings in the exposed site. Wind strength varied from 0-8 m/s but was most frequently below 3 m/s. In general the evening winds were slightly calmer than those of the mornings.

Nine 'epsilon' tsetse traps were deployed baited with acetone, octanol and 3-propyl phenol in all traps, plus 4-methyl phenol in traps specifically for *G. pallidipes*. On the first day approximately 100 *G. pallidipes*/trap were captured before the trial commenced. Very few *G. morsitans* were present in the area. A further 20 traps were subsequently placed throughout the area with four of these deployed in areas inaccessible by road thus positioned and attended by helicopter. Pre-spray catches generally averaged about 50 *G. pallidipes*/trap/day.

Operational results

The number of hours flown per activity is summarized in Table 10.

Table 10 Summary of aircraft hours according to activity

Activity	Hours				
	cycle 1	cycle 2	cycle 3	cycle 4	Total
Positioning	1.3	2.5	2.3	2.6	8.7
Calibration	0.5		0.6		1.1
Survey	0.4				0.4
Traps	2.7	1.0	1.7	0.5	5.9
Boundary spraying	0.3	1.8		0.9	3.0
Ferry to blocks	1.0	1.0	1.0	1.0	4.0
Turns	0.75	0.75	0.75	0.75	3.0
Block spraying	4.85	5.05	4.65	5.15	19.7
Total	11.8	12.1	11.0	10.9	45.8

The 'efficiency' of this operation, expressed as the percentage of total flying hours used for operational spraying (100/45.8 x 19.7) was 43%. This compares favourably with fixed-wing operations such as Mashumbi 1988 when the efficiency over the entire operation was 44.94%. If the positioning time had not been such a high proportion of the total hours, e.g. if the aircraft had been deployed one time and remained on site until the operation was completed, the efficiency would have increased to about 50%.

The 'activity' rate (the number of km² treated/hour) was much lower than that of the 1988 fixed-wing operation:

$$\frac{\text{total area treated } 126\ \text{km}^2 \times 4 \text{ applications}}{\text{total hours } 45.8} = 11\ \text{km}^2/\text{h}$$

The 1988 operation had an overall activity rate of 28.72 km²/h which is fairly standard. The low helicopter rate was due to the inordinately high percentage of positioning time and the relatively small block treated.

Physico-chemical results

Physico-chemical monitoring indicated a good distribution of droplets within an acceptable size range. The corrected values for VMD were slightly higher than for fixed-wing operations but considering the relatively slow speed of the aircraft and the use of wind-driven atomizers the results were surprisingly good. The mean VMDs taken for all sites over all four cycles varied from 23 μm to 29 μm. Comparing the VMDs between valleys, hillsides and ridges, droplets collected in the former were on average slightly larger at 30 μm while the average for the other sites was 26 μm. Corrected VMDs for droplets collected in flat, open sites during the 1988 fixed-wing operation were typically within the range 18 - 25 μm during the first two cycles when 30% ec endosulfan was used.

The droplet numbers, corrected for sampler efficiency, averaged over 1000/cm^2 for the first three applications and again this was a good result although it was considerably lower than the mean number/cm^2 of 3614 recorded in the flat, open terrain of the 1988 operation. There was no significant difference between the mean number/cm^2 for the first three cycles. The reduction in dosage rate from 24 to 20 g/ha, achieved by lowering the flow rate, resulted in a considerable reduction in droplet numbers.

To assess the value of helicopter spraying it was necessary to monitor aerosol penetration and distribution in various types of terrain and compare with results obtained in similar terrain treated by fixed-wing aircraft.

There was no significant difference between droplet numbers collected on hillsides and on ridges, but the number collected in valley bottoms was substantially lower. The hillsides and ridges were exposed sites but they were still in undulating terrain. The number of droplets recovered varied from a few hundred/cm^2 to 11 516 and averaged 1500 to 1800 droplets/cm^2. An 'array' site monitored during the 1988 operation was comparable terrain and the fixed-wing aircraft deposited a mean number of 276 droplets/cm^2 during cycles 1 and 2 when a similar 30% ec was applied. In such situations, where the fixed-wing aircraft must maintain a safe height, estimated between 150 and 1000 ft over the 1988 'array' site, the helicopter was able to follow the terrain and seldom exceeded 200-300 ft.

The 'gorge' site monitored in 1988 was similar to a 'valley' site monitored during this trial. At both locations the aircraft maintained a fixed height above the samplers and droplets results were comparable. A mean of 676 droplets/cm^2, VMD 31 μm at the gorge during cycles 1 and 2 in 1988 and 555 droplets/cm^2, VMD 31 μm with the helicopter. Where the aircraft simply fly over a 'difficult feature' such as a deep valley and do not attempt to follow the contours one would expect the fixed and rotor wing results to be similar.

Entomological results

After the first application trap catches dropped to zero four days after the spraying was completed. This was an unusually long delayed effect and, since there was a corresponding reduction in the daily temperatures, the result might have not been entirely due to the spraying.

After the second cycle the effect was more rapid and the trap catches immediately went down to zero in all but one trap. The temperature was fairly constant during the spraying and the result did appear to be due to the insecticide. The third cycle provided further support as the catches again went to zero in all traps and the temperature remained constant.

The apparent reduction to zero could have been due to reduced activity from sub-lethal dosing, i.e. the flies were morbid and were not being attracted to the traps. Without control over reinvasion this possibility could not be eliminated. However, reducing the last application to 20 g/ha we attempted to confirm that the dosages were close to the critical minimum. The fourth application confirmed this because four days after treatment the traps were still catching relatively high number of tsetse.

It was therefore concluded that:

(a) the dosage of 20 g/ha is too low for *G. pallidipes* in this type of terrain;

(b) 24 g/ha is close to the critical minimum;

(c) the reduction of tsetse number to zero after cycles 1 and 3, albeit for one day only after which reinvasion occurred, probably indicated that the treated adult population had been eliminated.

The trial strongly suggested that the use of helicopters in rugged terrain is a viable technique. The pilots were able to operate in this extremely demanding environment and even without sophisticated navigation equipment maintained accurate flight paths.

Satellite navigation would have been a tremendous help and would probably eliminate the need for ground support.

The distribution of insecticide and the size range of droplets recovered in the tsetse habitat was acceptable and, overall, was an improvement on the results obtained during the 1988 operation. The amount of drift was considerably less than in flat terrain, possibly because the drifting insecticide was obstructed by the undulating terrain, i.e. it did not drift up and down the valleys and ridges. Droplet deposition was also quite rapid but might have been due to relatively low wind speeds. Considering these factors and the variability of the wind direction in rugged terrain it would be prudent to reduce swathe width for future trials or operations.

The flying charges of Z$412/km^2 could be substantially reduced if the helicopter was used operationally (as opposed to a trial) and especially if it were combined with a fixed-wing operation so that 'fixed charges' could be shared (Allsopp, 1991).

THE '*PALLIDIPES* PROBLEM'

This study was carried out by Robert Fenn and a report was submitted to the RTTCP Co-ordinator (Fenn, 1991). This report is summarized below.

Despite continued success of the SAT against *G. morsitans* there was increasing concern over the discovery of small residual populations of *G. pallidipes* in treated areas. This includes more than 30 flies over approximately 10% of the 5000 km^2 treated with endosulfan in 1987 and a scattered population throughout the 1988 trial area sprayed with deltamethrin.

With improved trapping methods it was possible to detect and eliminate residual populations but this was clearly not ideal. The ASRDP therefore instigated a study at Rekomitjie Research Station in the Zambezi Valley to identify any inherent inadequacy of the SAT.

The survival of a small proportion of *G. pallidipes* has usually been attributed to the greater tolerance of *G. pallidipes* compared with *G. morsitans* and particularly to the increased tolerance of old female flies as suggested by laboratory studies (Harris, unpublished data; Kwan *et al.,* 1982). These studies were however, usually made without detailed ovarian dissection and on flies reared in laboratory colonies. Our study investigated the effect of species, age and pregnancy on the tolerance of field caught tsetse exposed to aerosol applications of endosulfan.

While it is not possible to relate LD_{50} values obtained in the laboratory to dosages applicable in the field, indications may be apparent by comparison of data for *G. morsitans,* which is eradicated by aerial spraying, with that for *G. pallidipes*. Further, by identifying the most tolerant sections of the *G. pallidipes* population, those most likely to survive an insecticide application can be identified. Once any differences become apparent, it is necessary to translate the information into practical suggestions that may be used to enhance the technique in the field.

It is not possible to apply a known volume of insecticide in aerosol form (except by means of sophisticated and time consuming techniques such as mature aerosol placement) and the amount of insecticide impinging on the fly has to be estimated retrospectively. This is possible by adding a fluorescent tracer to the insecticide formulation which may be washed from the treated fly by a suitable solvent and analysed quantitatively by fluorimetry. A simple calculation can then be made to determine the volume of formulation containing this quantity of tracer and hence the amount of active ingredient on the fly.

Materials and methods

Formulation

Insecticide was supplied by Hoechst as a 20% ec aerial spraying formulation (Thiodan). Controls were treated with a blank Thiodan formulation containing an inert bulking agent instead of the active ingredient. For the purposes of this study the 20% ec was diluted with blank formulation to produce a 4.0% solution. Uvitex OB was used at a concentration of 4.0% weight by volume as a fluorescent tracer.

Fluorimetry

Fluorimetric analysis was carried out using a Perkin Elmer LS-2B filter fluorimeter with an excitation filter of 375 nm and emission wavelength set to 435 nm. This was calibrated using pure hexane as the zero and a standard solution of 3 ng/ml Uvitex in hexane. Background readings were assessed by passing washings from untreated flies through the calibrated fluorimeter and found to be equivalent to 0.88 ng/ml Uvitex. All fluorimetric estimates were corrected accordingly.

Each fly, having been held since treatment in a new soda glass bottle, was washed to remove the tracer by addition of 4 ml of hexane. The bottles were shaken three times during a 30 min standing period, a 2 ml sample analysed and the flies and bottles discarded. Readings from the fluorimeter were noted against the individual code number assigned to each fly.

The wind tunnel

A horizontal wind tunnel 2.1 m long and 20 cm internal diameter was fabricated from 0.2 cm sheet steel with an open section, 50% of the circumference and 0.5 m long, providing access through which flies were inserted for treatment. This was closed during spraying by a 1.5 m sliding 'sleeve'.

Using a Gilson Pipetman small quantities of insecticide (1-4 μl) were pipetted on to the atomization surface of a spinning top aerosol generator which, at 500 rps, produced an aerosol of VMD 17 μm.

Air flow was generated by a centrifugal fan situated at the exhaust end of the tunnel. The air speed within the tunnel, measured with a hot wire anemometer, varied between 0.9 and 1.1 m/s depending on external conditions. After passing the treatment area the air was filtered before being vented to the atmosphere.

A 'honeycomb' of slightly less diameter than the tunnel was constructed from 3 cm lengths of 2.3 cm diameter metal tubing to hold the fly tubes in position during spraying.

Treatment of flies

Two species of tsetse fly are found in abundance at Rekomitjie, *G. pallidipes* and *G. morsitans*.

Flies were collected in 15 x 8 x 8 cm cages attached to an odour baited F3 trap enhanced with carbon dioxide. Each cage held 15-20 flies which could be collected in under 5 min and, when full, was placed in a cooled box.

Having been held overnight in an insectary at an average temperature of 30°C, flies were fed by securing the cages against an ox. Once fed each fly was transferred to a 3 cm tube of 1.9 cm diameter plastic conduit with gauze glued over one end and sealed with a second piece of gauze secured over the open end using an elastic band. These tubes were then placed in a honeycomb.

During transfer the sex and species of each fly was noted and those that appeared starved (abdomen curved over) or moribund (remaining on their back) were discarded. The honeycomb was placed in the tunnel, the aperture sealed and the aerosol applied.

After treatment flies were transferred to 7 ml soda glass bottles with loosely attached, aluminium lined, screw caps. The spray tubes were discarded. Each bottle contained a strip of filter paper to provide a perch for the fly and to absorb moisture from faeces. The bottles were labelled with the flies' individual code numbers and placed in plastic trays with a second tray inverted on top providing a lid to reduce draughts.

The flies were kept in a controlled environment cabinet at 25.0°C (± 1.0°C) and 75% rh (±3%) for 48 h and were checked for mortality at 24 h intervals. Death was defined as total lack of movement, a fast and convenient distinction.

After 48 h all flies, including survivors, were frozen to await dissection. All female flies were dissected for ovarian age category and uterus content, these details were noted against each fly's individual code. Uterine dissection provides an approximation of age as the position of eggs in the ovaries indicate the number of pregnancy cycles that have occurred (Mulligan, 1970).

During dissection flies were handled on a small, acetone washed, piece of aluminium foil to prevent loss of the fluorescent tracer. After dissection each fly was returned to its original bottle together with the aluminium foil. The filter paper was removed and discarded.

Data analysis

The data were recorded for each fly and then transferred to a database under the individual fly code numbers. Programmes written in the database's programming language allowed manipulation of the data.

Probit analysis was used to establish and compare LD_{50}s and LD_{99}s. In order to obtain suitable classes for analysis, the relevant data were arranged in ascending order of active ingredient (a.i.)/fly and divided into sub-groups containing approximately equal numbers. The numbers dead at 24 and 48 h were counted for each sub-group and the dose was taken as the arithmetic mean of the a.i./fly. Class size was determined by the number of flies available while maximizing the number of classes.

Results

Table 11 gives the numbers of *G. pallidipes* and *G. morsitans* used in the study. The numbers of flies used in the analysis are significantly lower than the totals caught as those of dubious fitness were discarded. Some dissection data on age and reproductive condition were lost as flies were stored for several days and some decomposition occurred.

Table 11 Total numbers of *G. pallidipes* and *G. morsitans* used

G. morsitans		*G. pallidipes*	
Female treated	307	Female treated	3778
control	29	control	508
total	336	total	4286
Male treated	77	Male treated	590
control	12	control	86
total	89	total	676
TOTAL	425	TOTAL	4962

Mortality

The 24 h LD_{50} for *G. pallidipes* males and females was 7.50 ng and 15.21 ng respectively, while at 48 h, it was 4.45 ng and 9.37 ng.

Data for *G. morsitans* proved less significant due to the small number of flies involved and the high control mortalities.

Uterus content

An egg or first instar larva in their uterus imparted no significant tolerance to endosulfan compared with the non-pregnant female. The presence of a second and particularly third instar larva significantly increased the female's tolerance to the insecticide.

Females with a second instar larva were approximately 1.5 and 2.0 times more tolerant to endosulfan at 24 and 48 h respectively, than those with less developed larvae. A third instar larva increased tolerance by a further 2.0 and 2.4 times (24 and 48 h respectively) and was thus 3.0 and 4.8 times more tolerant than non-pregnant flies.

Ovarian age category

A significantly different LD_{50} was found between age categories zero and five but no trends, such as an increase in tolerance with age, were apparent. Twenty-four hour LD_{50}s ranged between 9.68 ng for category zero to 17.48ng for category five. Forty-eight hour results varied between 5.56 ng for category zero and 12.50 ng for category five.

Discussion

This study confirms the significant difference in LD_{50} for females of *G.pallidipes* and *G. morsitans* at both 24 and 48 h found by other workers. This was not apparent for the *G. morsitans* males, probably due to the limited number caught and their high control mortality. Since female *G. pallidipes* are shown to be more tolerant to endosulfan than both males of the same species and *G. morsitans* of either sex, field application rates sufficient to eradicate female *G. pallidipes* should suffice for the entire population of both species.

Researchers (Burnett, 1962; Harris unpublished data) found a significant difference in tolerance between teneral females and 'old females'. Under this premise and to minimize ecological impact and insecticide cost it is normal operational procedure to reduce application rates once old flies have been eliminated by the first cycle. Dosages used for aerial spraying in Zimbabwe vary according to the target species and terrain. Against *G. morsitans,* applications of 20-25 g/ha reducing to 14-16 g/ha by the fourth and fifth cycles are generally used. In rugged terrain, or against *G. pallidipes,* the starting dose of 25 g/ha is not reduced below 18 g/ha.

This study indicates that physiological age has little effect on tolerance, while in the later stage of pregnancy tolerance may increase three fold. Thus the practice of progressively reducing the dose is brought into question. Young female flies emerging after a spray application will be as tolerant as their older counterparts in the pre-spray population when their first larvae develops to the second or third instar. To eliminate these flies will therefore require the same application rates as used in the first cycle.

It is not possible to relate laboratory results directly to field dosage rates but indications are that the minimum application rate required in the first cycle to eliminate adult *G. morsitans* will not be sufficient where *G. pallidipes* is the target. A computer model (Johnstone and Cooper, 1986) based on the likelihood of an exposed tsetse picking up drifting droplets during spraying, estimates that an application rate of 30 g/ha would give 99.99% mortality in 'normal conditions'.

After the first cycle, the SAT is timed to eradicate adult flies before the first pregnancy cycle is completed and larvae deposited. Applications then continue for the duration of the pupal period until there are no pupae remaining underground.

It has been reported (Irving, 1968; Kwan *et al.,* 1982) that endosulfan is transferred to the larva in 'milk' secretions, thus reducing the toxic amounts within the female fly. This has obvious control significance (Langley, 1977). Maximum milk gland cell diameter occurs two-thirds of the way through the pregnancy cycle (Tobe *et al.,* 1973; Langley and Pimley, 1975; Ma *et al.*, 1975) which is consistent with the increased tolerance in the later stages of pregnancy found in this study.

The timing of sequential aerial applications is based on the relationship between daily average temperature and the time from adult emergence to first larviposition. A recent review of this method (Lumamba, 1990) indicated it was sufficiently accurate but there are indications (Hargrove, personal communication) that the 'first larval period' can be shorter than current estimates. In this event adult females could be carrying second or third instar larvae before the next treatment commences. With present procedures these flies are likely to receive a sub-lethal dose and a residual population will remain after spraying.

This study suggests two ways in which possible reasons for failing to eliminate *G. pallidipes* might be avoided:

(a) an application of about 30 g/ha should be applied for all cycles using the intercycle period commonly accepted for SAT;

(b) after a first application of 30 g/ha subsequent dosage rates would be reduced as usual but the interspray periods shortened to prevent pregnancy developing beyond the first instar. Taking this option an extra application may be required to cover the pupal period.

There are environmental and cost implication for both options. The former option of maintaining a high dose for all cycles could increase non-target effects and would increase the cost of insecticide. This should, however, be less expensive than adding a further application. The latter option would also increase the total amount of insecticide used but spread over time and avoiding repeated high doses. There would be increased cost from the insecticide and flying time for the extra cycle.

SUMMARY OF CONTROL ACTIVITIES 1986-89

1986 CHESA, ZIMBABWE

Operation statistics

Treatment area:	3200 km^2
Number of aircraft:	4
Flight intervals:	200 m
Aircraft speed:	250 kph
Insecticide:	endosulfan 30% and 20% ec
Dosage rates (g/ha):	22, 18, 16 (part of cycle 2), 14,14,14

The SAT operation in the Chesa communal farming area of Mashonaland was smoothly executed and achieved an excellent entomological result. An area adjacent to the aerial spraying block, incorporating the Umfurudzi Game Reserve which supported a very high tsetse density, was treated with targets only at a density of 4/km^2. A 1 km deep barrier of targets at a density of 25-30/km^2 separated the aerial spraying and target treatment area and effectively prevented reinvasion between SAT cycles (Hursey *et al.*, 1987). The entire area, which was only infested with *G. morsitans*, remains tsetse free to this date.

1987 CHOMA/KALOMO, ZAMBIA

This operation was funded by the EC Special Action Programme. The contractor was therefore not committed to quite the same stringent control over operational procedures and monitoring that would have applied within the RTTCP.

Operational statistics

Treatment area:	4500 km^2
Number of aircraft:	4
Flight intervals:	200 m
Aircraft speed:	250 kph
Insecticide:	Thiodan 'T' ULV 30% and 20%
Dosages required (g/ha):	22, 18, 14, 14, 14
Flow rates (l/min):	6.11, 5.00, 5.83, 5.83, 5.83
(l/km^2):	7.33, 6.00, 7.00, 7.00, 7.00

Dosages achieved

	(g/ha)	(l/min)	(l/km^2)
cycle 1 (aborted)	22	6.11	7.33
cycle 1 (restarted)	15	4.17	5.00
cycle 2	18	5.00	6.00
cycle 3-5	14	6.07	7.00

Navigation equipment was leased from Litton Aero Products, USA. The Litton PICS (Photogrammetric Integrated Control System) is an automatic aerial survey camera system linked to Litton's LTN-72 inertial track guidance system (ITGS). Only the ITGS was relevant to this operation. Litton claim the equipment has mission geographic parameters definable to a resolution of 60 ft with dynamic position computations and survey line spacings to a resolution of 6 ft. In theory it appeared to have the required capability to take the aircraft from the base to an entry point in the treatment area, maintain a straight flight path, execute an accurate procedure turn and re-enter on a reciprocal flight path with an incremental separation of 250 m.

Eco-technical monitoring

From the first cycle it was apparent that the spray equipment was not performing as expected and the contractor was not following the normal maintenance procedures which are clearly specified in the Micronair handbooks. The spray gear had no in-line filters or flow stabilizing tubes between the insecticide tanks and atomizers and the clamp rings holding the blades on the atomizer were being overtightened. The co-pilots experienced considerable difficulty in achieving and maintaining the required flow rates. The suggestion was made, several times, that the spray gear should be washed out daily as this was obviously not being done. Not surprisingly, blocked turbines etc., caused a number of aborted sorties and when the flow rates were subsequently checked on the ground it was obvious that cycle 1 had been overdosed (the probable cause of fish kills).

A Micronair (UK) Ltd engineer was invited (at ASRDP cost) to visit the operation and help to improve the performance of the spray equipment. He confirmed that none of the systems had filters or flow stabilizing tubes, none of the systems were fitted with variable restrictor units, which are essential to keep the systems pressurized (which in turn is necessary for accurate flow regulation), and, of the three flow turbines, one had been installed backwards, one was the wrong size and one was damaged.

Had these faults not been rectified the insecticide applications would have been very patchy, with tanks probably running dry in mid-sortie. There would have been many more aborted sorties and substantial wastage of chemical. This may simply have disrupted the operation but could have resulted in premature termination or further environmental contamination.

Following specialist attention the spray equipment performed satisfactorily and problems were largely confined to normal operational wear. Dump seals occasionally developed leaks and were immediately replaced. One atomizer had a persistent leak which was not cured until the new teflon seal installed by the Micronair specialist was replaced with the original neoprene seal. Seals in the side loading couplings deteriorated quite rapidly and were replaced as required. One entire coupling developed a persistent leak and had to be replaced.

Summary of the 1987 Zambian operation

The contractor had not prepared well for this operation and initially it was technically inefficient. There was also a number of major misfortunes, each of which might well have been sufficient to terminate the operation had the determination to see it through to a successful conclusion not persisted.

On the first sortie of the first night one aircraft had to make a forced landing in a field and during the same night a large fish kill occurred in a dam immediately alongside the SEMG camp. During later cycles an insecticide dump immediately after take-off led to cattle deaths and finally there was a tragic (non-spraying) aircraft accident in which the contractor and the EC Manager were killed.

Most of the early technical problems were eventually rectified, though not all – apparently because of financial restrictions. The air crews and the technicians worked extremely hard to keep the aircraft flying and to keep the operation on schedule. The long cycles which characterized the early cycles gradually decreased and the fifth cycle took only five and a half nights.

Aer Kavango's tender, though cheap, was awarded against the advice of the Regional Co-ordinator and ASRDP team leader. From a regional point of view it was important for Zambia to make a start on their control activities. This may well have clouded the final decision, which was made so late that it was almost impossible for any contractor to have been fully prepared to start on time. In the event they achieved a satisfactory result – but at a cost – not least of which a loss of EC confidence in the technique of sequential aerial spraying. Many lessons were learned from this operation: the need for absolute clarity and tight specification in tender and contractual documents, the value of eco-technical monitoring and perhaps most important of all the potential dangers in selecting tenders on the criterion of 'low cost'.

1987 MZARABANI, ZIMBABWE

Operational statistics

Area treated:	5000 km^2
Number of aircraft:	5 (usually 2/3 per formation)
Aircraft speed:	250 kph
Swathe width:	250 m
Insecticide:	endosulfan 30% and 20% ec
Dosage rates (g/ha):	22,20,16,14,14

A total area of 5000 km^2 was treated and tsetse were eliminated throughout, except for an area of about 400 km^2 near the Mozambique border and the western spray boundary. The spraying even appeared to be successful along the extremely hilly escarpment. About 30 flies were caught in the 400 km^2 area after the fifth cycle. Under instructions from the TTCB a sixth localized application was tried but failed to remove this residual population. After a few months they did appear to die out and no tsetse were captured in this area until August 1988 when seven more were caught. Some were close to the western target barrier and could have reinvaded. Mark/recapture studies prior to the commencement of the 1987 operation had shown marked flies passing through the barrier on the western boundary in the area where the survivors were subsequently found. As a result of the mark/recapture experiment the barrier was widened before aerial spraying commenced but the number of targets was not increased.

Survival of *G. pallidipes* in relatively flat terrain of the Zambezi Valley was totally unexpected. The localized cycle 6 was applied in an attempt to eliminate this residual population but was unsuccessful. Physico-chemical monitoring did not conclusively explain why tsetse might have survived but a number of possible reasons were suggested. For example, the swathe width might have been too wide at 250 m. The combination of low flying (in the very flat and, in parts, cultivated land) with a larger than normal droplet from the new, slightly less volatile, Thiodan 'T' formulation, might have substantially reduced the available dosage through more rapid sedimentation. The winds were too light for droplets to impact on tsetse (though they eliminated *G. morsitans*) etc.

The reason is perhaps a combination of the above factors. Due to the proximity of the steep Zambezi Escarpment the area was sprayed along east-west flight paths. In the north of the block away from the escarpment, where the survivors were found, winds were generally light and easterly, i.e. the aircraft were flying along the wind direction rather than across it. The bulk of the insecticide might, therefore, have been deposited along a narrow plume immediately below the flight path with relatively little drift between swathes. This would have been exacerbated by the 250 m swathe, the larger, less volatile droplets and low flying. The fact remains, however, that *G. morsitans* were eliminated so if the above reasoning is correct it would appear that the low dosage between swathes was sufficient to kill *G. morsitans* but not *G. pallidipes*.

1988 MASHUMBI, ZIMBABWE

Operational statistics

Treatment area:	2000 km^2
Number of aircraft:	3
Navigation:	Doppler 72B/TANS/SGP 500
Atomizer:	Micronair AU4000 (x 2 fuselage mounted)
Swathe width:	250 m
Aircraft speed:	265 kph
Insecticide:	deltamethrin (ulv)
−concentration	0.35%
−dosage	0.25 g/ha for each of 5 applications
−tracer	0.1% Uvitex OB
Application rate	7.14 l/km^2
Flow rate	7.74 l/min at 146 knots

This operation was the culmination of several years work by Wellcome, NRI, ASRDP and TTCB to investigate the suitability of deltamethrin as an alternative to endosulfan for aerial spraying. Wellcome started testing their insecticide in 1983, i.e. before the EC asked for a protocol to be prepared. This was initially to be a guideline for manufacturers and suppliers wishing to introduce their products to the RTTCP but which eventually became an instruction with strict SEMG stipulations. The protocol had three phases.

1. Laboratory work to estimate a suitable dosage.

2. Small-scale field trial (about 400 km^2) to assess the non-target effects without causing any widespread environmental damage and a preliminary assessment of the effects against tsetse.

3. Large-scale (1000 km^2) trial as a definitive assessment of effects on tsetse and non-targets.

Phases 1 and 2 were designed to illustrate to the RTTCP that a particular insecticide appeared suitable and were to be entirely funded by the manufacturers. Phase 3 was to satisfy the RTTCP that the insecticide (which had already met the manufacturers own stringent safety etc., requirements) did in fact meet their own, specific and strict requirements. The phase 3 trial and its interpretation were to be entirely under the jurisdiction of the RTTCP. As such they would be funded by them as part of the national control programmes for which the manufacturer would be granted the privilege of providing the insecticide without tendering.

Phase 3 of the deltamethrin trials should have been carried out in 1987. There were, however, problems. It was thought by some that the dosage recommended by Wellcome, i.e. 0.25 g/ha, was too low. The SEMG were concerned that drift from an adjacent endosulfan treatment would confuse the deltamethrin trial. To overcome this it was suggested that the area be extended to 2000 km^2 thus making it possible to distance the deltamethrin surveys from the endosulfan applications. This was acceptable to the SEMG but approval was not given until 1988 when this trial took the place of the control operation.

Summary of the Mashumbi operation

The first cycle achieved about a 90% reduction. The second cycle, was brought forward a few days in a token effort to overcome this poor result and it succeeded in eliminating all adult tsetse of both species. A dosage rate of 0.25 g/ha did, therefore, seem sufficient to eliminate a population which included some older and pregnant flies, if not a normal age distribution. However, after cycles 3,4 and 5 a small number of young adult *G. pallidipes*, mostly in ovarian age category 1, was discovered. These had emerged after cycle 2 but had subsequently survived one or more applications.

From a control point of view this was not a satisfactory result. It could have been improved by 'mopping up' with targets or perhaps sterile males but no such action was taken. A more widespread residual population remained after the 1988 operation than after 1987 but the treatment area for 1988 began with a much higher density and widespread *G. pallidipes* population. The results for 1987 and 1988, i.e. for endosulfan and deltamethrin, were therefore considered comparable.

TRAINING

Although not specifically listed in the ASRDP's terms of reference, training was considered to be an important activity and every effort was made to pass on knowledge or details of technological developments whenever the opportunity arose.

ASRDP personnel and visiting scientists, for example, application specialists from NRI, were regularly called upon to collaborate in training courses. The ODA/FAO Leadership Training Course and FAO's Middle Management Course, both for tsetse and trypanosomiasis control staff, invariably included a visit to aerial spraying operations. Lectures were given on such general topics as operational procedure, physico-chemical monitoring and meteorology. Practical training was also provided for staff using such techniques as ovarian dissection or insecticide droplet analysis.

Two staff members of the Zambian Department of Veterinary Services and Tsetse Control were attached to the ASRDP for comprehensive training in 1988. They took an active part in all aspects of the aerial spraying operation in Zimbabwe under the supervision of the ASRDP. Their training concluded with a formal examination which clearly showed they had both absorbed the general principles of the SAT and also indicated particular aptitudes each had for aspects of the work.

Two bio-aeronautics graduates from the Cranfield Institute of Technology, UK were attached to, and co-funded by, the ASRDP in 1986, 1987 and 1988. Having recently concluded their MSc studies these graduates assisted the ASRDP during aerial spraying operations and gained unique practical experience. One of these graduates remained with the ASRDP and undertook the *'pallidipes'* study in 1989 and 1990. Another was assigned to an ODA/TC project managed by NRI and designed a prototype aerosol generator for use in tsetse and other pest control situations.

DISCUSSION

The ASRDP was formed to combine the experience and resources of NRI and the EC to speed up the development of a technique to control tsetse flies in southern Africa. Not unexpectedly, the project evolved and as we increased our understanding of the aerial spraying technique new problems came into focus; notably the difficulty of eliminating *G. pallidipes*.

The high cost of aircraft hire limited the research scope and much of the research and development was dependent upon collaboration with commercial operators. This was a research constraint but did provide an operational framework for practical and realistic development. This collaboration together with frank and open discussion between researchers and contractors resulted in significant improvements to safe operational procedure; safe for the operators, for the support staff and for the environment. It led to a broader interpretation of environmental monitoring which had been largely reactive. The result was pro-active, eco-technical monitoring to identify and rectify potential problems in application procedure etc., before they can cause environmental contamination. This achievement was not anticipated when the original terms of reference were drawn up but resulted from the multidisciplinary nature of the RTTCP. It should serve as a model for any future aerial spraying activities or indeed any mechanized technology which distributes bulk pesticides.

One result which would not have been achieved without the co-operation and support of an operational contractor was the development of a navigation system. The importance of a robust navigation system with a range of specific capabilities was clearly illustrated as were the limitations within which the system should be operated.

The descent of tiny aerosol droplets from aircraft is severely influenced by a number of factors, predominantly air movements, and they can drift for many kilometres. Their distribution in the tsetse habitat is normally variable but control results indicate that, under normal circumstances, there are sufficient droplets throughout the treatment to reach and kill tsetse flies. Such variation and extensive drift might suggest that accurate navigation is unnecessary but experience clearly shows the high possibility of leaving areas unsprayed through navigational error; especially if this coincides with a change in wind direction. Also, while one area receives an underdose, another almost inevitably is overdosed and this is probably the most common cause of fish mortality when spraying with endosulfan.

Throughout the 1980s the TTCB improved their capability to detect low density tsetse populations. Odour-bait technology added a new dimension to entomological surveys and resulted in a dramatic increase in the use of impregnated screens or targets for control. As a result, aerial spraying in Zimbabwe stopped employing ground sprayed DDT barriers to prevent the reinvasion of tsetse into treated areas and replaced them with target barriers. In fact, neither barrier as used at present could guarantee to prevent reinvasion. The value of barriers to protect aerial spraying areas and other control situations is still to be clarified but the potential for combining aerial spraying and targets in an integrated manner was clearly illustrated.

Improved survey sensitivity increasingly indicated that aerial spraying was highly effective against *G. morsitans* but was not eradicating *G. pallidipes*. The ASRDP was extended beyond 1989 to address this important issue. It was concluded that *G. pallidipes* requires a higher dosage rate of insecticide than those which have historically been used in southern Africa. This is consistent with results in Somalia where *G. pallidipes* were successfully eliminated from an area of 3000 km^2 but with dosage rates in excess of 30 g/ha. It now remains to test this conclusion under operational conditions as this was unfortunately not possible within the life of the ASRDP.

The *'pallidipes* problem' should be kept in perspective and should not be invoked to contra-indicate the selection of aerial spraying for tsetse control. Wherever the sequential, low dosage application of insecticide aerosols has been properly carried out to control tsetse flies the reduction in tsetse abundance has been dramatic; this includes *G. pallidipes* and applies to many countries in Africa. There have been instances when contractors, for whatever reason, were simply not equipped or experienced to perform this highly technical operation and this reflects unfairly on the technique. When carried out to the high standard that has become the hallmark of the RTTCP aerial spraying is highly effective, environmentally acceptable and safe. It cannot guarantee the elimination of every single tsetse fly in a treatment area at a stroke, except perhaps *G. morsitans*, but then neither can any other control technique. If this is accepted and the control strategy is designed accordingly then aerial spraying can make a most valuable contribution.

It is not appropriate in this report to discuss in detail whether tsetse control strategies should be radically changed. Suffice it to say that the aim need not always be eradication since this is where most have come to grief. Barrett (1992) discussed the economic value of aiming for a much lower level of control. The potential for community participation in 'mopping up' residual tsetse populations or maintaining the reduced population at its post-treatment level has never been fully assessed.

A major consideration for the ASRDP was the applicability of fixed-wing aerial spraying for rugged terrain. The conclusion, again, was that eradication could not be guaranteed but as with the *'pallidipes* problem' this should also be kept in perspective.

Much of the terrain in Zimbabwe from which tsetse have successfully been eliminated was extremely rugged. The pervasive nature of drifting insecticide is unaffected by all but the most severe topographical or geological features. Spraying tsetse in the Zambezi Escarpment represented the ultimate terrain challenge and even there some remarkable results were achieved. Success against tsetse was, however, uneven like the insecticide distribution. This was not simply a terrain problem but was compounded by local meteorology.

Aerial spraying should not automatically be discounted because a treatment area includes broken terrain, undulations, river valleys etc. Increasing severity will, however, require a correspondingly greater understanding of meteorological vagaries, more attention to surveys, since the chance of survival will also increase and an extremely professional approach by the spraying contractor. At some point these considerations will count against fixed-wing spraying but with experienced advice many areas which appear at first sight too difficult for aerial spraying may well prove within its capability.

Where fixed-wing aerial spraying is discounted on the grounds of terrain severity the use of helicopters might be considered. The trial in 1988 was most encouraging even though no attempt was made to protect the treatment area from reinvasion and the pilots navigated by eye! Based on experience to date, the use of helicopters in the most severe terrain which serves as a habitat for tsetse could confidently be expected to achieve excellent control, if not eradication. In such terrain it is difficult to visualize any technique being any more convenient or more successful. Satellite-aided navigation has become more widely available since 1988 and would greatly facilitate the pilot's operational capabilities.

Further trials with helicopters in severely rugged terrain would be most useful to confirm, or otherwise, this initial perception.

REFERENCES

Allsopp, R. (1984) Control of tsetse flies (Diptera:Glossinidae) using insecticides: a review and future prospects. *Bulletin of Entomological Research,* **74**: 1-23.

Allsopp, R. and Coutts, H. H. (1977) Aerial spraying trials with ulv azemethiphos, crotoxyphos and endosulfan for tsetse fly control in Botswana. *COPR Miscellaneous Report,* No. 32.

Allsopp, R. and Hursey, B. S. (1986) *Integrated Chemical Control of Tsetse Flies (*Glossina *spp.) in Western Zimbabwe 1984-1985.* Harare: Tsetse and Trypanosomiasis Control Branch, Department of Veterinary Services.

Andrews, M., Flower, L. S., Johnstone, D. R. and Turner, C. R. (1983) Spray droplet assessment and insecticide drift studies during large scale aerial applications of endosulfan to control *Glossina morsitans* in Botswana. *Tropical Pest Management,* **23**(3):239-248.

ASRDP (1987) *ASRDP Report,* No. 4. Harare: Regional Tsetse and Trypanosomiasis Control Programme for Southern Africa.

ASRDP (1988) *Annual Report.* Harare: Regional Tsetse and Trypanosomiasis Control Programme for Southern Africa.

Allsopp, R. (1991) *ASRDP Final Report.* Volume 2. *A Practical Guide to Aerial Spraying for the Control of Tsetse Flies* (Glossina *spp.*). Chatham: Natural Resources Institute.

Barrett, J. (1992) *Cost Studies of Trypanosomiasis Control in Southern Africa.* Chatham: Natural Resources Institute. (Unpublished)

Burnett, G.F. (1962) The susceptibility of tsetse flies to topical applications of insecticides. III. The effects of age and pregnancy on the susceptibility of adults of *Glossina morsitans* Westw. *Bulletin of Entomological Research,* **53**: 337-345.

Cooper, J. F., Dobson, H. M. and Johnstone, D. R. (1987) A rotary sampler for coarse aerosol sampling: sampling rate and impaction efficiency corrections to give a good estimate of airborne drops. p. 40. In: *Aerosols: Their Generation, Behaviour and Application.* First Conference, Aerosol Society, Loughborough, 37: 40.

Du Toit, R. and Kluge, E. B. (1949) The application of insecticides by aircraft for the control of tsetse flies in South Africa. *British Science News,* **2** (20): 246-250.

Fenn, R. (1991) *The* 'Glossina pallidipes *Problem'. Studies on the Effect of Pregnancy and Physiological Age on the Tolerance of Tsetse Flies to Endosulfan Aerosols.* Report to the EC Regional Tsetse and Trypanosomiasis Control Programme, Harare.

Hadaway, A. B. and Barlow, F. (1965) Studies on the deposition of oil droplets. *Annals of Applied Biology,* **55**:267-274.

Hocking, K. S., Parr, H. C. M., YEO, D. and Anstey, D. (1953) Aircraft applications of insecticides in East Africa. IV – The application of a coarse aerosol in a savanna woodland containing the tsetse flies *Glossina morsitans* and *G swynnertoni. Bulletin of Entomological Research,* **44**: 627-640.

Hursey, B. S. and Allsopp, R. (1984) *Sequential Applications of Low Dosage Aerosols from Fixed-wing Aircraft as a Means of Eradicating Tsetse Flies (*Glossina *spp.) from Rugged Terrain in Zimbabwe.* Harare: Department of Veterinary Services, Tsetse and Trypanosomiasis Control Branch.

Hursey, B. S., Whittingham, G. W. and Chadenga, V. (1987) The integration of insecticidal techniques for the control and eradication of *Glossina morsitans* in North-East Zimbabwe. In: *19th Meeting of the International Scientific Council for Trypanosomiasis Research and Control, Lome, Togo, 1987* OAU/IBAR, Nairobi.

Irving, N.S. (1968) The absorption and storage of insecticide by the *in utero* larva of the tsetse fly *Glossina pallidipes* Aust. *Bulletin of Entomological Research,* **58**: 221-226.

Johnstone, D. R. and Cooper, J. F. (1986) Forecasting the efficiency of the sequential aerosol technique for tsetse fly control. *Pesticide Science,* **17**: 675-685.

Johnstone, D. R., Allsopp, R., Cooper, J. F. and Dobson H. M. (1987 a) Predicted and observed droplet deposition on tsetse flies *(Glossina morsitans)* following aerosol applications from aircraft. *Pesticide Science,* **22**: 107-121.

Johnstone, D. R., Cooper, J. F. and Dobson, H. M. (1987 b) The availability and fall-out of an insecticidal aerosol dispersed from aircraft during operations for the control of tsetse flies in Zimbabwe. *Atmospheric Environment,* **21** (11): 2311-2321.

Johnstone, D. R., Cooper, J. F., Flower, L. S., Harris, E. G., Smith, S. C. and Turner, C. R. (1989) A means of applying mature aerosol drops to insects for screening biocidal activity. *Tropical Pest Management,* **35**(1): 65-66.

Kwan, W. H., Gatehouse, A. G. and Kerridge, E. (1982) Effects of endosulfan on pregnant females of *Glossina morsitans morsitans* Westwood (Diptera: Glossinidae) and their offspring. *Bulletin of Entomological Research,* **72**: 391-401.

Langley, P. A. (1977) Physiology of tsetse flies (*Glossina* spp.) (Diptera: Glossinidae): a review. *Bulletin of Entomological Research,* **67**: 523-574.

Langley, P. A. and Pimley, R. W. (1975) Quantitative aspects of reproduction and larval nutrition in *Glossina morsitans morsitans* Westw. (Diptera, Glossinidae) fed in vitro. *Bulletin of Entomological Research,* **65**: 129-142.

Lee, C. W., Parker, J. D., Kultzer, H., Baldry, D. A. T., Bettany, B. W. and Tunstall, J. (1980) The experimental application of insecticides from a helicopter for the control of riverine populations of *Glossina tachinoides* in West Africa. VII. Studies on the physical properties of sprays of endosulfan and deltamethrin applied to *G. tachinoides* habitats in the R. Komoe Valley, Upper Volta. *Tropical Pest Management,* 26: 377-384.

Lumamba, D. (1990) *Studies on the Effects of Temperature on Larval Development of Glossina Species.* Final report of the Overseas Development Administration research scheme R3970A. London: Overseas Development Administration.

Ma, W. C., Denlinger, D. L., Jarlfors, U. and Smith, D. S. (1975) Structural modulations in the tsetse fly milk gland during a pregnancy cycle. *Tissue and Cell,* **7**: 319-330.

Mulligan, H. W. (1970) Determination of the age of *Glossina* in adult and puparial stages. In: *The African Trypanosomiases.* London: George Allen and Unwin/Ministry of Overseas Development.

Spielberger, U., Na'isa, B. K. and Abdurrahim, U. (1977) Tsetse (Diptera: Glossinidae) eradication by aerial (helicopter) spraying of persistent insecticides in Nigeria. *Bulletin of Entomological Research,* **84:** 589-598.

Tobe, S. S., Davey, K. G. and Huebener, E. (1973) Nutrient transfer during the reproductive cycle in *Glossina austeni* Newst.: histology and histochemistry of the milk gland, fat body and oenocytes. *Tissue and Cell,* **5**: 633-650.