Pro-Poor
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Initiative

Comparable Costings of Alternatives for Dealing with Tsetse: Estimates for Uganda

Alexandra Shaw, Steve Torr,
Charles Waiswa and Tim Robinson

A Living from Livestock

FAO FIAT PANIS

PPLPI Working Paper No. 40

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PREFACE

This is the 40th of a series of Working Papers prepared for the Pro-Poor Livestock Policy Initiative (PPLPI). The purpose of these papers is to explore issues related to livestock development in the context of poverty alleviation.

Livestock is vital to the economies of many developing countries. Animals are a source of food, more specifically protein for human diets, income, employment and possibly foreign exchange. For low income producers, livestock can serve as a store of wealth, provide draught power and organic fertiliser for crop production and a means of transport. Consumption of livestock and livestock products in developing countries, though starting from a low base, is growing rapidly.

The current debate on how best to deal with tsetse-transmitted trypanosomiasis focuses on issues of scale, sustainability and cost. Much of the discussion on the costs of the different methods is based on comparisons from different countries, calculated at different times, including different cost components for projects with different management structures, duration and objectives. An updated set of costs, taking into account issues of timing and based on parameters from one location, was urgently needed.

We hope this paper will provide useful information to its readers and any feedback is welcome by the authors, PPLPI and the Livestock Information, Sector Analysis and Policy Branch (AGAL) of the Food and Agriculture Organization (FAO).

Disclaimer

Authors

Alexandra Shaw is an economist who was worked extensively on the problem of tsetse and trypanosomiasis in Africa. She and a group of colleagues have recently developed the concept of 'mapping the benefits' which could be realised from more effective control of this disease and she hopes to extend this approach along with the costing work described here to the rest of the IGAD region as part of its Livestock Policy Initiative.

Steve Torr is a Reader in Veterinary Entomology at the University of Greenwich's Natural Resources Institute. He has over 25 years experience of working on various aspects of tsetse biology and control, including eight years on attachment to the Zimbabwe Department of Veterinary Services as a tsetse biologist. His current research interests include the development of web-based decision support tools to assist in the planning of interventions against tsetse.

Charles Waiswa has worked as a researcher on tsetse and trypanosomiasis specialising in studies on transmission. He is a Senior Lecturer and Head, Department of Veterinary Medicine, Makerere University where he is responsible for the running of clinical studies at undergraduate and postgraduate levels. He is involved in activities relating to Stamp Out Sleeping Sickness in Uganda which is a Private-Public Sector partnership.

For more information visit the PPLPI website at: http://www.fao.org/ag/pplpi.html
or contact: Joachim Otte - Programme Coordinator of the Pro-Poor Livestock Policy Facility
Email: Joachim.Otte@fao.org Tel: +39 06 57053634 Fax: +39 06 57055749
Food and Agriculture Organization - Animal Production and Health Division Viale delle Terme di Caracalla 00153 Rome, Italy

Timothy Robinson works for the Pro-Poor Livestock Policy Initiative (PPLPI), based in FAO's Livestock Information, Sector Analysis and Policy Branch (AGAL). He is responsible for developing information systems and also for activities in the Horn of Africa, including the IGAD Livestock Policy Initiative, under which the work reported here will be further developed.

Acknowledgements

The authors would like to acknowledge the encouragement and support received from Raffaele Mattioli as well as the helpful and detailed comments received from Peter Holmes and Udo Feldmann. Many useful insights into the problem were provided by Ian Maudlin and Sue Welburn and also by Andrew Brownlow, Robert Dransfield, Mark Eisler, Eric Fèvre, Guy Hendrickx, Glyn Vale and William Wint. FAO's Pro-poor Livestock Policy Initiative is thanked for funding this work, under a grant from the UK's Department for International Development. Particular thanks are due to William Olaho Mukani, Director of Animal Resources in the Ministry of Agriculture, Animal Industries and Fisheries (MMAIF) in Uganda: William and his colleagues have encouraged and supported this work throughout. The Coordinating Office for the Control of Trypanosomiasis in Uganda (COCTU) is also acknowledged for facilitation and dissemination of these results to stakeholders in Uganda.

Keywords

Tsetse, tsetse control, costs, choice of technique, PATTEC.

Date of publication: 17 April 2007

ACRONYMS

ADB	African Development Bank
ADF	African Development Fund
AU-IBAR	African Union - Inter-African Bureau for Animal Resources
COCTU	Coordinating Office for Control of Trypanosomiasis in Uganda
DFID	Department for International Development (UK)
FAO	Food and Agriculture Organization of the United Nations
FITCA	Farming in Tsetse Controlled Areas (Ethiopia, Kenya, Tanzania, Uganda)
GIS	Geographic information system
HAT	Human African trypanosomiasis
IAEA	International Atomic Energy Agency
ILRI	International Livestock Research Institute
ISCTRC	International Scientific Council for Trypanosomiasis Research and Control
ITC	Insecticide-treated cattle
LIRI	Livestock Research Institute, Uganda
MAAIF	Ministry of Agriculture, Animal Industries and Fisheries, Uganda
NGOs	Non-Governmental Organisations
NRI	Natural Resources Institute, Chatham, UK
PAAT	Programme Against African Trypanosomiasis
PATTEC	Pan-African Tsetse and Trypanosomiasis Eradication Campaign
PAAT-IS	PAAT Information System
PPLPI	Pro-poor Livestock Policy Initiative, FAO, Rome
PCR	Polymerase chain reaction
SAT	Sequential aerosol technique
SIT	Sterile insect technique
T&T	Tsetse and trypanosomiasis
UBOS	Uganda Bureau of Statistics
UNHS	Uganda National Household Survey
UTTC	Uganda Trypanosomiasis Control Council
WHO	World Health Organization

EXECUTIVE SUMMARY

As the activities and capacity of veterinary institutions have declined across sub-Saharan Africa, control of trypanosomiasis has been left largely in the hands of farmers, who spend US$ 30 to 40 million a year on trypanocides to protect their livestock. The launching of the Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) has mobilised support from African leaders and funding which may provide the continent with a window of opportunity to intervene effectively to control the disease. But only if its initial programmes are seen to be successful – in terms of the areas targeted, the goals set, their effectiveness in dealing with tsetse and their cost – will governments, donors and livestock keepers invest in further tsetse control rather than continue to rely on trypanocides.

In this context it is vital that not only the entomological efficacy of the different techniques at our disposal is studied, but also their relative cost. Most studies of the costs of tsetse control have analysed different control methods based on comparisons from different countries, calculated at different times, including different cost components for projects with different management structures, duration and objectives (see Shaw, 2004). The only two studies undertaken which consistently compare the costs of more than two techniques in one country at one point in time are Barrett (1997) for Zimbabwe and Brandl (1988) for Burkina Faso.

This report presents the initial results from a comparative costing exercise for Uganda. It takes as it starting point the area extending to 40,000 km^2 initially targeted by PATTEC for the creation of a tsetse-free zone in south eastern Uganda, located in a crescent around Lake Victoria's north-western shore and extending to cover the southern part of the Lake Kyoga basin. In this area the predominant fly is Glossina *fuscipes fuscipes* and some areas have also been shown to have localised infestations of *G. pallidipes* (Magona *et al*., 2005, Waiswa *et al*., 2006). Using the most recent census data for Uganda, the core infested area of 20,000 km^2 along Lake Victoria was estimated to contain some 750,000 cattle and 4.9 million rural inhabitants, more than half of whom (2.6 million) subsist on less than $1 a day.

This study integrated approaches from three disciplines. Firstly, geographic information system (GIS) techniques were used to combine modelled tsetse distributions (http://www.fao.org/ag/AGAinfo/programmes/en/paat/maps.html) with estimates of cattle and human populations. Secondly, a tsetse population dynamics model (Vale & Torr, 2005; http://www.tsetse.org/) was used to simulate over time the effects of four methods: traps deployed at densities of 10 km^{-2} against *G. fuscipes* or at 4 km^{-2} against savannah tsetse; different densities of cattle treated with insecticide applied to the whole body or only the legs and belly (ITC); aerial spraying using the sequential aerosol technique (SAT) and the sterile insect technique (SIT) following suppression for 90 days using an insecticidal technique. Thirdly, published information on the costs of the different techniques was combined with data from ADB *et al*. (2004) and current prices for staff and materials in Uganda. These were incorporated in an Excel™ spreadsheet so that prices, quantities and other assumptions could be varied and sensitivity analyses be conducted. The economic analysis included the preparation and monitoring time required for each technique, its field cost as well as administrative overheads and preparatory studies. Following standard practice for livestock projects, all costs were discounted to their present value at the time point when active tsetse control in the field began, using a discount rate of 10%.

These costs were divided into the field costs (the direct costs of deploying the tsetse control method in the field), the cost of accompanying studies (tsetse surveys, parasitological surveys, environmental monitoring and socio-economic studies) and the administrative overheads. The studies and overheads were taken to be the same for each method in the baseline analyses, but possible reductions were examined for some scenarios. The results for isolated populations showed that the costs km^{-2} of the different techniques increased in the order: ITC (US$ 130–400), traps for savannah flies (US$ 400-500), SAT (US$ 500–600), traps for *G. fuscipes* (US$ 900) and if SIT needed to be included (US$ 1,000–1,300). Compared with earlier studies, refinements to all approaches have reduced their relative costs thus narrowing the differentials among them. The results for non-isolated tsetse populations showed that using a barrier on one side for a three-year period to prevent reinvasion increased costs by 15–60%, with the higher level increases associated with the use of a target barrier alongside savannah flies and the lower cost increase with the use of ITC as a barrier.

This study's aim was to provide a rigorous framework for comparing the cost of different techniques and a series of consistent cost estimates that can be improved on by further field work and trials. These estimates are particularly sensitive to some of the assumptions made – for example the price of flying time for aerial spraying and deployment of sterile males. The cost of SIT is affected by the lead time for developing a colony to produce sterile males and the added cost of a suppression technique. There are likely to various be circumstances in which combinations of tsetse control techniques are the most suitable approach, particularly where several species of *Glossina* are present. Accordingly, the calculations undertaken here make it possible to estimate the costs of combined approaches and to select the most cost-effective. Recent research has shown that the restrictive application of insecticide greatly reduces the cost of ITC. Ongoing trials in Uganda will help to quantify this in a field context (Welburn *et al*., 2006). Thus, although the real costs of the different methods have fallen slightly over time and the differentials between them have narrowed, there remain substantial differences in costs. For this reason it is essential that planners give careful thought to choice of technique on economic as well as on entomological grounds. The selection of cost-effective measures needs to be a component of all poverty alleviation strategies and this study highlights the need to include it in the field of tsetse and trypanosomiasis control.

Inevitably, there remain unanswered questions both about the costs of the techniques and about their efficacy in different situations and against different species of *Glossina*. The questions about costs mainly reflect either uncertainty about technical efficacy or questions about the type of organisation, and in particular the level of administration, management and accompanying studies required. The questions about the relative efficacy of the different techniques will partly be answered by further field experience. However, in the light of the decisions facing planners in this field at the moment, it is strongly recommended that an effort be made firstly to review past tsetse control and elimination schemes and identify their strengths and weaknesses and the reasons for their successes and failures and, secondly, that the tsetse community consults the PAAT platform and applies the criteria and guidelines elaborated by the PAAT community for integrated control of the disease. These guidelines reflect a consensus, and should be extended to describe fully the situations in which each technique performs best and to define where each is suitable, unsuitable or needs to be deployed alongside another technique to produce the best results.

1. INTRODUCTION

The 1980s and 1990s have seen Africa's livestock keepers facing an increasingly difficult situation in their attempts to deal with trypanosomiasis. The activities and capacity of veterinary institutions have declined across sub-Saharan Africa, while attempts to replace the government-funded services through privatised provision of veterinary care have met with mixed results so that there is an urgent need to find new paradigms for their provision (Leonard, 2000, Holden, 1999). Furthermore, a parallel decline in the funding and coverage of the continent's tsetse control units has occurred, with many units closing down or becoming absorbed in departments with a wider remit. As a result, the control of trypanosomiasis in livestock has been left largely in the hands of farmers, who spend some US$ 30 to 40 million a year on trypanocides to cure or protect their livestock from this disease (Geerts and Holmes, 1998 and Holmes *et al*., 2004). Changing patterns of livestock keeping, such as the rearing of zebu cattle in the Central African Republic and in the sub-humid zones of many West African countries and increasing use of draught power in eastern and south-central Africa have put more livestock at risk from the disease. The decline in control activities was paralleled in the human field, with human African trypanosomiasis re-emerging as a major public health problem at the end of the 1990s (see WHO, 2006). Its control relies mainly on finding and treated infected individuals, especially in the areas where the *gambiense* form of the disease is found (WHO, 1998) whereas in the areas where the *rhodesiense* form of the disease is found in cattle-rearing communities, cattle are often the major reservoir and need to be treated as well as people (see Hide *et al*., 1996, Fèvre *et al*., 2005).

Faced with this situation, in the field of tsetse control[1], a lively debate is currently going on as to the best method for dealing with tsetse and with trypanosomiasis in livestock and people. The debate focuses on issues of scale, sustainability and cost – all of which have important implications for choice of technique. In recent years there has been an increasing move towards adopting 'area-wide' approaches in the hope of creating substantial tsetse-free areas, where farmers will be able to raise livestock, especially cattle, without recourse to trypanocides. This view has led to, and found its champion in the vocal and well-organised Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) which has succeeded in putting tsetse control firmly on Africa's leaders' agendas; a position of prominence that it has never before had. PATTEC has also succeeded in mobilising funds for dealing with the disease with the initial plans for creating tsetse-free areas in 3 West African countries (Burkina Faso, Ghana and Mali) and three eastern African countries (Ethiopia, Kenya and Uganda) as outlined in ADF (2004).

With the unprecedented high profile currently accorded to trypanosomiasis and the availability of substantial funding to deal with it comes a major responsibility to ensure that these initial programmes are seen to be successful. This success must be in terms of the areas selected for intervention, the goals set, their effectiveness in dealing with tsetse and their cost. Only if such success can be demonstrated will governments, donors and livestock keepers invest in further tsetse control rather than continue to rely on trypanocides. If these projects fail it is very likely that T & T interventions will fall down the priority ladder as rapidly as they ascended it.

[1] In this paper, the convention has been adopted of using the word 'control' as defined by Thrusfield (1995) "the reduction of the morbidity and mortality from disease… a general term embracing all measures intended to interfere with the unrestrained occurrence of disease, whatever its cause". Control in the context of T & T thus covers all measures from treating clinically sick people and livestock to the eradication of the vectors or pathogens. The definition selected for eradication is the one frequently used in veterinary medicine: "the regional extinction of an infectious agent". In this work the word elimination is considered more appropriate to describe the creation of tsetse-free zones, such that transmission ceases and therefore the disease incidence within these areas falls to nil.

It is against this background that this report seeks to address the need to find and test a simple approach for comparing the costs of different interventions so as to guide decision-making on choice of technology at a time when a greater range of more carefully tested and refined options for dealing with tsetse exists than ever before.

2. CURRENT KNOWLEDGE ON TSETSE CONTROL COSTS

Records of the costs of the different activities undertaken in order to control tsetse have been kept since this type of work began, *e.g.* Wilson (1953) reporting on ground-spraying and bush-clearing in Kenya. As more detailed and large scale campaigns were undertaken, their costs were also analysed, for example by Davies (1964 and 1971) for ground-spraying operations in northern Nigeria. The work done there was studied in more detail by Putt *et al.* (1980), who analysed the costs of some 65 ground and helicopter spraying operations which had been undertaken in Nigeria since 1955. Their analysis covered not just the costs incurred in the field (for insecticide, labour, flying time and staff allowances, vehicle running and depreciation) but also included the overheads for administration and ancillary operations such as barriers and re-sprays where reinvasions occurred. Broadly speaking, this analysis showed that, although the field costs for ground-spraying were only just over a third of those for helicopter spraying, this difference was largely eroded once the various overheads were included, since aerial spraying involved a leaner operation with most of the costs being subsumed in the charge for flying time. However, in common with other economic analyses undertaken at the time, it was thought appropriate to include an analysis using shadow prices for foreign exchange (thus artificially increasing the price of goods purchased abroad) and for labour (thus artificially decreasing the cost of locally employed unskilled labour). The use of such shadow prices was recommended in order to favour projects which saved on foreign exchange and created local employment, much as poverty weightings are used today to favour projects targeting poor beneficiaries. Using these shadow prices had the effect of making the cost of ground-spraying less than two thirds that of helicopter spraying. Although dated, this is the only analysis of this type undertaken for tsetse control activities, and as is discussed below, the findings are of relevance to the current debate.

Another west African study, in the Sideradougou area of Burkina Faso (Brandl, 1988) undertook a rigorous comparison of the costs of dealing with riverine tsetse (*G. palpalis* and *G. tachinoides*) over a range of time periods for:

- tsetse elimination using SIT (with 2 months prior suppression using traps) plus 3 trap barriers maintained for 5, 10 or 15 years;
- tsetse elimination using helicopter spraying plus 3 trap barriers maintained for 5, 10 or 15 years; or
- ongoing control for 5, 10 or 15 using traps years at different densities (at the time it was not known that these techniques are capable of eliminating a population).

The results were as follows:

- over 5 years, control using traps was the cheapest and elimination using SIT was the most expensive;
- over 10 years, control using traps at low density (300 m spacing) and elimination using helicopter spraying were the cheapest and elimination using SIT was the most expensive application; and
- over both 15 and 20 years, elimination using helicopter spraying was the cheapest and using SIT was the most expensive.

The cost of controlling trypanosomiasis using chemotherapy were also calculated, in high challenge situations and over long periods this exceeded the costs of both tsetse control and elimination by whatever method. However, in low challenge situations, chemotherapy was always the cheapest option.

The most comprehensive study of the costs of different techniques to control tsetse was undertaken by Barrett (1997) for Zimbabwe. Barrett analysed the four main techniques being used in Zimbabwe in the late 1980s and 1990s, looking in detail at all the field operation parameters (staffing levels, vehicle use, timing, *etc.*) and his summary table, as updated by Budd (1999) is given below (Table 1). Barrett's costs included what he defined as direct costs (insecticide, flying time, cost of targets and manpower, vehicles and equipment) and indirect costs for camp and access provision, but excluded overheads for administration and management by headquarters staff, staff training, tsetse and trypanosomiasis surveys and research. They can thus be characterised as very comprehensive 'field costs'.

Apart from these studies, most of the analyses of the costs of tsetse control have been confined to one country and one control operation, often being linked to project evaluations and therefore tending to remain relatively inaccessible in the grey literature. Also, since they were undertaken at different points in time, as well as in different countries, comparisons are difficult. Most studies and almost all scientific publications have confined themselves to analysing field level costs, tending to assume that administrative overheads are broadly the same for all technologies. This is not necessarily the case, as the analysis by Putt *et al.* (1980) demonstrated this is due both to intrinsic differences in how different techniques work and to extrinsic factors, reflecting project structure, donor exigencies and country- and location-specific organisational attributes.

Table 1: *Field costs for tsetse eradication in Zimbabwe.*

Operational characteristics			**Range of costs for tsetse eradication (1999 US$ km^{-2})**			
Terrain	Fly species	Cattle presence	Ground spraying[a]	Targets[b]	Aerial spraying	Insecticide treated cattle[c]
Rugged	*G. morsitans*	Absent	340-390	315-385	340-430	Not considered
Rugged	*G. pallidipes*	Absent	340-390	220-290	Not considered	Not considered
Flat	*G. morsitans*	Few	265-315	220-290	345-435	Not considered
Flat	Mixed	Present	265-315	220-290	435-535	50-120

Source: Adapted from Budd (1999) who in turn updated the costs produced by Barrett (1997); the conversion factor from 1990 Zimbwe $ to 1999 US $ was 2.08, adjusting for the change in the exchange rate and assuming an annual inflation rate of 2.5%.

Notes:

[a] Figures for spraying using DDT, using Deltamethrin would increase the costs by 70%.

[b] Targets costed assuming only two services after initial deployment.

[c] ITC is only possible where sufficient cattle are present. The lower figure is for adding an insecticide which would kill tsetse to dips controlling ticks, the higher for the use of a pour-on preparation at a cattle density of 15 km^{-2}.

None of the studies cited above is recent, and in the interval the techniques have been substantially refined and improved. Recent cost estimates for all techniques can be found in the various articles in Maudlin *et al*. (2004) and these are summarised below (Table 2).

Table 2: *Recent calculations of the costs of different tsetse control techniques.*

Tsetse control technique	Estimated costs in US$ km^{-2} (Date)	Control or eradication	Included/excluded in costs	Source, country
Insecticide treated cattle (ITC): pour-on case study with 44 cattle km^{-2}	60 (1996)	Annual control cost	Included: pour-on, tsetse monitoring, farmers' time, time taken to apply to cattle, transport Excluded: tryps. monitoring and other research components	Woudyalew *et al.* (1999) Ghibe, Ethiopia
Aerial spraying using the sequential aerosol technique (SAT)	270 (2000/01)	Elimination	Included: operational costs for insecticide and aerial spraying contract	Allsopp & Hursey (2004) Okavango, Botswana
Targets	219 (1996)	Control	Field costs for Tsetse Control Division	Botswana Mullins *et al.* (1999)
	96 (1999)		Cost of contract for initial deployment	Allsopp & Hursey (2004)
	228 (1999)		Deployment plus retreating 2 x at 6 monthly intervals (incl. 60% damaged targets)	Allsopp & Hursey (2004)
Sterile insect technique (SIT) Standard: release of 55-100 sterile males km^{-2} *e.g.* southern and Eastern Africa	800 (2004)	Post suppression: elimination of fly population	Included: additional cost of breeding and releasing sterile flies for 18 months after initial suppression Excluded: management overheads and suppression costs	Feldmann (2004)
West African riverine systems: (10 sterile males km^{-2})	250-300 (2004)			General
Trapping (mono-pyramidal traps)	26 (1992)	Annual control cost	Included: all field level costs, capital items, local administration and salaries, donor costs Excluded: adaptive research	Shaw *et al.* (1994) Northern Côte d'Ivoire

Source: Adapted from Shaw (2004), references as cited.

3. MODELS AND METHODS

3.1 The Tsetse Control Techniques Analysed

The last two decades have seen significant refinements in all of the tsetse control techniques, which have tended to reduce their costs. A detailed analysis of these developments is outside the scope of this principally economic analysis. For an introduction into recent developments the reader is referred to Allsopp and Hursey (2004), Feldmann (2004), Vale and Torr (2004, 2005). In order to focus this analysis in the context of the current debate on choice of technique for area-wide interventions and the creation of tsetse-free zones, only those techniques which can be used on a large scale to eliminate as well as to control tsetse are considered. For this reason methods used by individual farmers to protect their cattle, such as zero-grazing in netted housing, smoke or repellents are not considered here. Ground-spraying, while shown to be very effective in controlling or eliminating tsetse on a large scale in northern Zimbabwe and northern Nigeria, has been left out of the analysis as, despite studies which have shown it to be environmentally acceptable, this technique has tended to be superseded by others that use less insecticide and/or do not use residual insecticides.

Also left out of the analysis are the necessary accompanying measures to deal with sleeping sickness in people and trypanosomiasis in the livestock population. Clearly, controlling the vector can interrupt transmission, but infected people need to be found and cured. Infected livestock also need to be treated, especially in those *rhodesiense* areas where cattle have been shown to be the main reservoir of the human disease (Onyango *et al*., 1966, Hide *et al*., 1996). While infected animals remain, there is also a risk of some low level transmission from biting flies. These trypanosomiasis measures are required whatever control technique is chosen and for this reason can be set aside from the analysis looking at the cost-effectiveness of the different area-wide approaches.

Accordingly four contrasting techniques were selected for costing out.

A) Traps

Traps rather than targets were selected for costing as stationary baits because these have been shown to be effective not just against *morsitans* (savannah) group flies but also against *palpalis* (riverine) group flies such as *G. fuscipes*, the fly found in south-eastern Uganda and south-western Kenya, in the areas selected by PATTEC for its initial project to create tsetse and trypanosomiasis-free zones. Furthermore, insecticide-treated traps have been used previously in this area as part of programmes to control tsetse so as to interrupt the transmission of human African trypanosomiasis (HAT) (Lancien, 1991, Lancien and Obayi, 1993). The costing approach used would apply equally well to targets.

B) Insecticide-treated cattle

The use of insecticide-treated cattle (ITC) has widely come to be regarded as an attractive and usually low-cost method of controlling tsetse. This technique offers the possibility of dealing with tick and tsetse problems simultaneously and can thus be integrated into farmers' existing tick control regimes. It involves livestock keepers and, to a far greater extent than other farmer-based tsetse control techniques such as traps and targets, is regarded by them as conferring a 'private' benefit to their own treated cattle, rather than conferring a public benefit to livestock in the area (Swallow and Woudyalew, 1994).

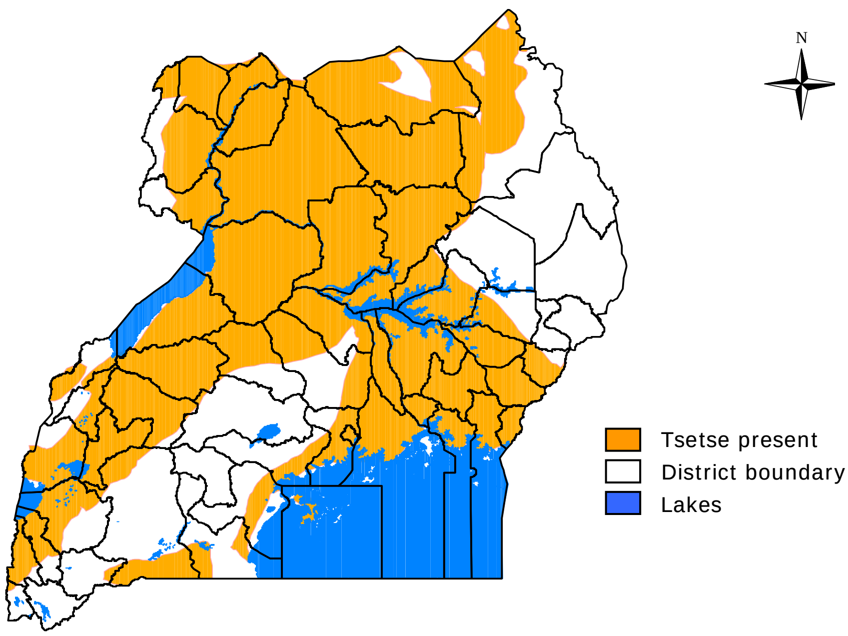
C) Aerial spraying

For aerial spraying, the technique currently most widely used is the sequential aerosol technique (SAT) whereby tsetse are sprayed with a non-residual insecticide at intervals designed to kill all adults initially, and then subsequently to kill young adults after they emerge but before they deposit larvae. Usually five cycles are required, at ~15 day intervals. This technique has most recently been very successfully deployed in Botswana's Okavango delta to deal with *G. morsitans centralis* (Allsopp and Hursey; 2004, Kgori *et al*., 2006). It has also been extensively used in areas of Zimbabwe. Numerous studies have confirmed that the level of insecticide usage is such that no appreciable short term and no long term environmental damage is caused (Allsopp and Hursey, 2004).

D) Sterile insect technique following suppression using another method

Lastly, following the success in eliminating tsetse on Unguja Island, Zanzibar, much interest has been shown in using the sterile insect technique (SIT) as a means of eliminating residual fly populations once the tsetse population of an area has been suppressed using an insecticidal method. Whereas the other techniques can be used either for ongoing control or suppression of fly populations, or to eliminate them, in the field of tsetse control, SIT is a technique specifically designed to deal with a small remaining population so as to ultimately achieve its elimination. It has been developed primarily with a view to dealing with situations where other techniques cannot completely remove the fly population. While SIT itself has no direct adverse environmental impact, accompanying suppression techniques do have limited impacts, as described above.

Figure 1: *Uganda tsetse distribution as illustrated in the 1990s.*



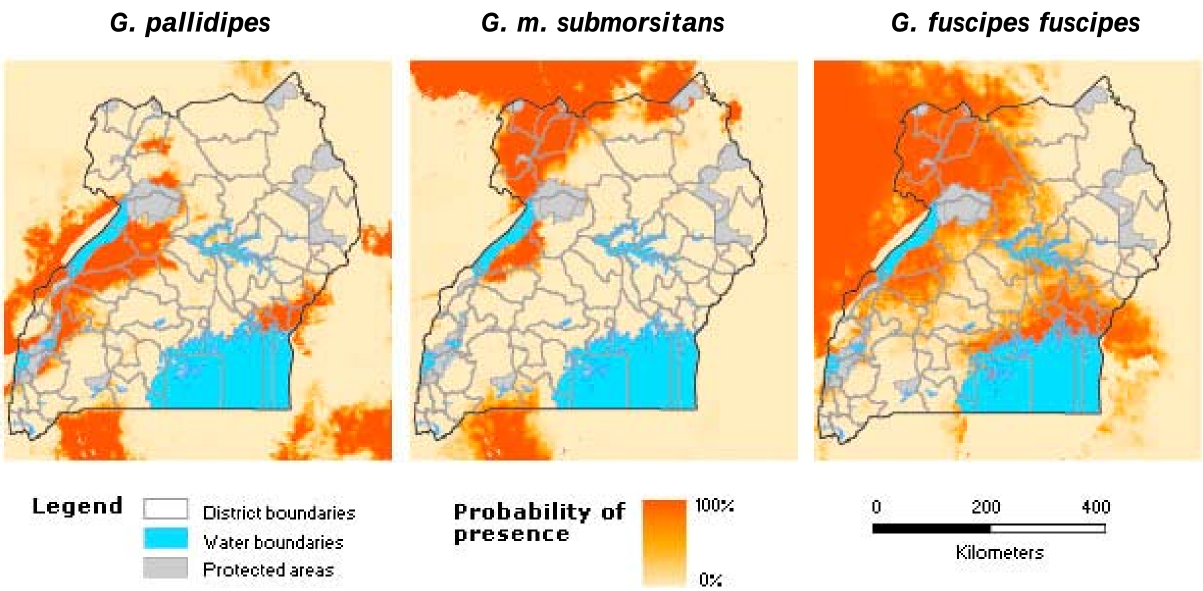
Source: Robinson (2002) – compiled from a series of data collected in the 1990s for nine species of tsetse in Uganda by the Livestock Department and Animal Health Research Centre, Ministry of Agriculture, Animal Industries and Fisheries (MAAIF).

3.2 The Project Area

This analysis has been undertaken with specific reference to the area of south-eastern Uganda currently identified by PATTEC for the creation of a tsetse-free zone as described in ADB *et al*., 2004 and the policies outlined in COCTU, 2004. This choice was dictated by a number of factors. First and foremost, it forms part of an ongoing assistance to the Government of Uganda to develop a framework to target tsetse and trypanosomiasis control activities and to decide which approaches would be most appropriate in different circumstances. Secondly, as discussed in Section 2, in order to understand better the economics of the different approaches, it is important that they be compared using a consistent costing methodology, based on prices applicable at one point in time and in one area. Thus selecting one country and one region is important, event for the type of *ex ante* costings being undertaken here. Thirdly, the part of Uganda selected provides a mix of factors which make an analysis of the tsetse and trypanosomiasis problem there a useful template – a mixed fly infestation, with potential for reinvasion from some but not all directions, a significant sleeping sickness and animal trypanosomiasis problem in the context of an integrated crop-livestock production system. It is also an area where considerable work has been done on the disease and where there is potential for ongoing field work to refine and improve cost estimates.

Uganda's tsetse distribution has not been comprehensively mapped recently. Nevertheless, since tsetse and trypanosomiasis have consistently been given a high priority by Uganda's veterinary and medical services, there has been a relatively high level of tsetse survey activity in recent years, particularly through the activities of the Livestock Research Institute (LIRI) and in association with projects such as the Farming in Tsetse-controlled Areas (FITCA) project. Figure 1 shows the tsetse distribution in Uganda as it was thought to be in the 1990's and Figure 2 shows the more detailed results of a more recent GIS exercise to map the major tsetse distributions around the Lake Victoria basin (Wint, 2002), based on predictive models and environmental data (see Robinson *et al*. 1997, Gilbert *et al*. 2001, Pender *et al*., 2001, Rogers and Robinson, 2004 for detailed explanations of the methodologies and data involved) Uganda's three main species, *G. pallidipes, G. morsitans submorsitans* and *G. fuscipes fuscipes* stretch across the country in a belt from northwest to southeast, with the populations apparently more fragmented and less dense in the central area around Lake Kyoga.

Figure 2: *Modelled distribution (probability of presence) of the three main species in Uganda.*

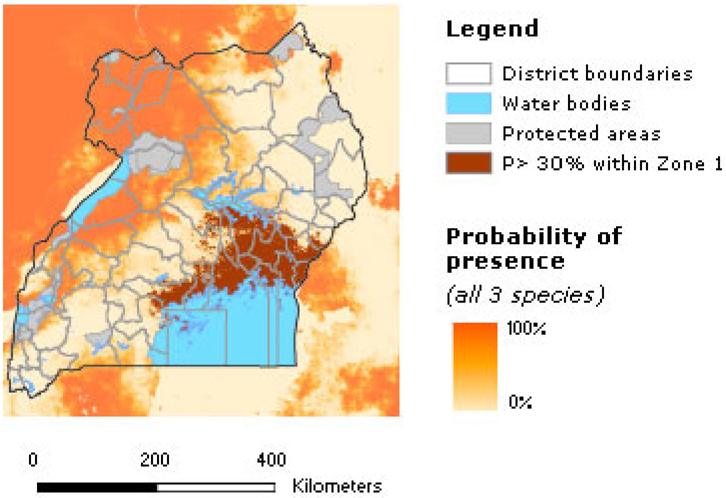


Source: Wint (2002).

The continuity of the tsetse distribution across the Lake Kyoga area has major epidemiological implications. This is due to the fact Uganda is unusual in being a country where HAT is present in both the chronic *gambiense* form found in West and Central Africa and in the more acute *rhodesiense* form which is found in eastern Africa and in whose epidemiology the animal reservoir plays an important role (see WHO, 1998 and 2006). The *gambiense* form has existed in the northwest of the country, whereas the *rhodesiense* form has been confined to the southeastern part of the country. Very recently, however, there has been a marked expansion in the area where *rhodesiense* is found, moving into Soroti district and northwest towards Lake Kyoga, so that there is a real and present danger of the two diseases meeting (Picozzi *et al*., 2005).

Throughout tsetse-infested Uganda, animal trypanosomiasis is recognised as a major constraint to cattle keeping. A recent study (Thuranira, 2005), conducted just over the border in Kenya's Busia district, estimated that farmers' potential income from livestock was reduced by nearly a half due to cattle deaths from endemic diseases, principally trypanosomiasis and tick-borne illnesses.

Figure 3: *Areas with 30% or greater probability of tsetse presence highlighting the Zone 1 project area.*



Source: produced using Wint's (2002) predicted maps (see Figure 2).

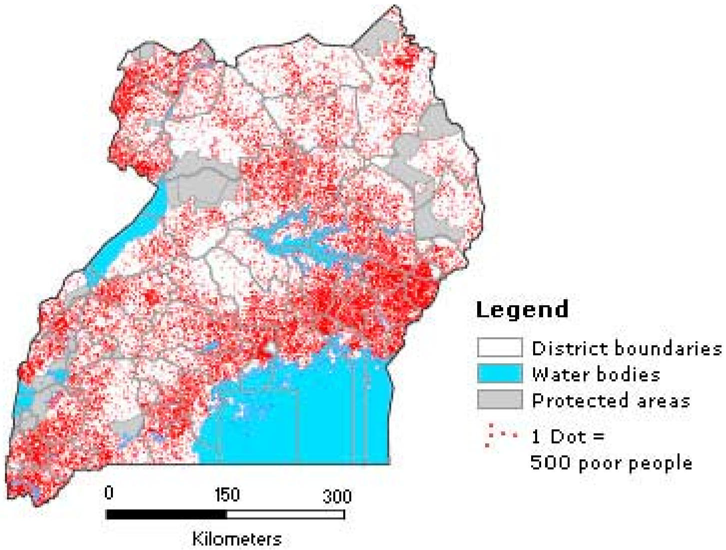
The area targeted by PATTEC for the creation of a fly-free zone in Uganda, illustrated in Figure 3, comprises a crescent around the shore of Lake Victoria, encompassing the southern part of the Lake Kyoga basin and over to the Kenya border, where it is planned that similar operations to control the fly will remove the reinvasion risk from that direction. The main fly present is *G. fuscipes*; there have also traditionally been thought to be a population of *G. pallidipes* in the area along the Kenya border. However, while surveys undertaken by FITCA at the end of the 1990s failed to reveal the presence of any *G. pallidipes* (personal communication R. Dransfield) despite there being populations of this fly on the Kenyan side of the border, recent surveys have shown that they are currently present (Magona *et al*., 2005 and Waiswa *et al*., 2006). The overall extent of the tsetse-infested area in the project area is not currently known. PATTEC has made provision for clearing four blocks of 10,000 km^2 (ADB *et al*., 2004). A GIS analysis, based on the Wint (2002) tsetse distributions, suggest that the core area lying in a crescent around Lake Victoria covers about 20,000 km^2. Combining the tsetse distributions with figures from Uganda Bureau of Statistics (UBOS) 2002 and 2004, this are was estimated to contain some 750,000 cattle and 4.9 million rural inhabitants, more than half of whom (2.6 million) subsist on less than US$1 a day.

In fact, from the point of view of poverty alleviation, this crescent is a key area. The area around Lake Victoria has been highlighted as having a high population of poor livestock keepers (Thornton *et al*., 2002). Recent work on poverty mapping at the PPLI, based on Uganda's recent censuses (UBOS, 2002, 2004) has confirmed this, as illustrated in Figure 4. This shows the numbers of poor rural households, and the concentration around Lake Victoria both mirrors the general population distribution and highlights the fact that this is an area where there is widespread poverty. For poor households, livestock represent both a hedge against adversity, being a resource which can be sold to cope with crises, a source of income and protein and eventually, for some livestock keepers, a means of rising above the poverty threshold.

The area around Lake Kyoga, on the other hand is a key area from the epidemiological point of view, as explained above, it is here that the threat of the two forms of HAT converging exists. For this reason, a project has been initiated to control tsetse using

ITC, in advance of the projected PATTEC activities. This work will yield valuable data on the efficacy and cost of ITC in the field in Uganda (Welburn *et al*., 2006).

Figure 4: *Poverty density in Uganda, 1992.*



Source: Rogers *et al*. (2006).
Note: Each dot represents 500 poor people living in rural areas. This map was produced by combining small area estimates of poverty incidence (Emwanu *et al*., 2003) with sub-county level rural population statistics from the 2002 housing and population census (UBOS 2002).

3.3 The Tsetse Model

Over the last twenty-five years a number of models has been developed and refined with the objectives of increasing our understanding of trypanosomiasis, tsetse and the ways in which they can be controlled and of quantifying the benefits to be gained from control, thus informing decision-making in this field. These have included:

- disease transmission models, notably Rogers (1988) and models comparing the impact of different control strategies on the disease (*e.g.* McDermott and Coleman, 2001);
- economic models, usually consisting of a cattle population dynamics model comparing cattle productivity in the absence and presence of the disease (*e.g.* Brandl, 1988, Shaw 1990 and Shaw *et al*., 2006) which were used to estimate the benefits of controlling the disease; and
- tsetse population dynamics models, most recently those described in Hargrove (2003a and 2003b) and Vale and Torr (2005).

Ideally, all three types would be integrated to model both the changes in the vector population and the disease incidence, and to link these to livestock productivity and control costs. In the past economic analyses have tended to focus on cattle productivity and have often had to make very general assumptions about the speed and extent of changes brought about by tsetse control. Therefore, a workable model which traces changes in the tsetse population as the result of control activities and which makes it possible to estimate the timing and calculate the cost of control activities has been needed for some time.

The model described in Vale and Torr (2005) is available at http://www.tsetse.org/ from where it can be freely downloaded. It was designed to act as an interactive source of information on the feasibility and eventual costs of different approaches to dealing with tsetse in a defined area and to be accessible to non specialists, in particular groups such as local government organisations, livestock keeper groups and NGOs. Like any population dynamics model, the basic structure of the model requires input of certain figures. In this case the following were needed:

- a starting population, here fixed at 5,000 wild female and 2,500 wild male tsetse km^{-2}, where 'wild' distinguishes the existing population from introduced reared flies, in particular released sterile males;
- age- and sex-specific death rates, the baseline rates for un-controlled tsetse populations are taken from the literature and then these are modified to account for the additional deaths due to the various tsetse control techniques, in line with the impacts that have been observed during experimentation and trials; and
- baseline birth rates, taken from the literature and, where SIT is the control technique being used, modified to account for the proportion of matings taking place with a sterile male.

It needs to be emphasized that the structure of this model does not incorporate any assumptions that would make the outcomes tend to favour one tsetse control technique over another. Like other population dynamics models, the outcome depends on the values assigned to the key variables – starting population, birth and death rates. To reinforce this neutrality sterile males have been assumed to be only somewhat less viable than wild males. The model allowed that the steriles were slightly less successful at mating (25% lower than wild males), less mobile (25% lower) and had a slightly higher death rate (25% greater). These figures are better than those for currently available sterile flies but reflect what might be achievable in time following successful research to improve the fitness of sterile males. The additional kill rates assumed for each technique fall within the observed bands and could be varied in order to check the sensitivity of the results to a range of values. For the model runs used in these calculations, traps were assumed to kill 2% of females a day when deployed against savannah group flies at a density of 4 km^{-2}, giving 8% per day mortality. Insecticide treated cattle were assumed to kill 3% of females a day, giving 12% per day mortality when deployed against savannah group flies at a density of 4 km^{-2}. SAT was run for 5 cycles, under ideal circumstances eliminating an isolated population in just under 6 weeks, after 4 cycles. The results from the model runs are summarised in Table 3, which shows the baseline calculations for the time taken to eliminate a population, with elimination being defined as the point at which fewer than 0.5 flies km^{-2} remained.

The results of these calculations highlight how differently the control techniques operate and perform, with the time taken to elimination varying between 39 and 351 days for isolated tsetse populations with a trouble-free operation. These differences have seldom been illustrated so clearly and tend not to be emphasized when the techniques are compared. They also point to the need to ensure that economic analyses clearly reflect time as well as cost if they are to illustrate valid comparisons. Figure 5 shows the graphs of the modelled reduction in fly populations using each of the four techniques for this baseline scenario, with isolated populations and elimination under ideal conditions. In Section 5, sensitivity analyses are conducted, looking at non-isolated tsetse populations and the implications of various set-backs in the control operations.

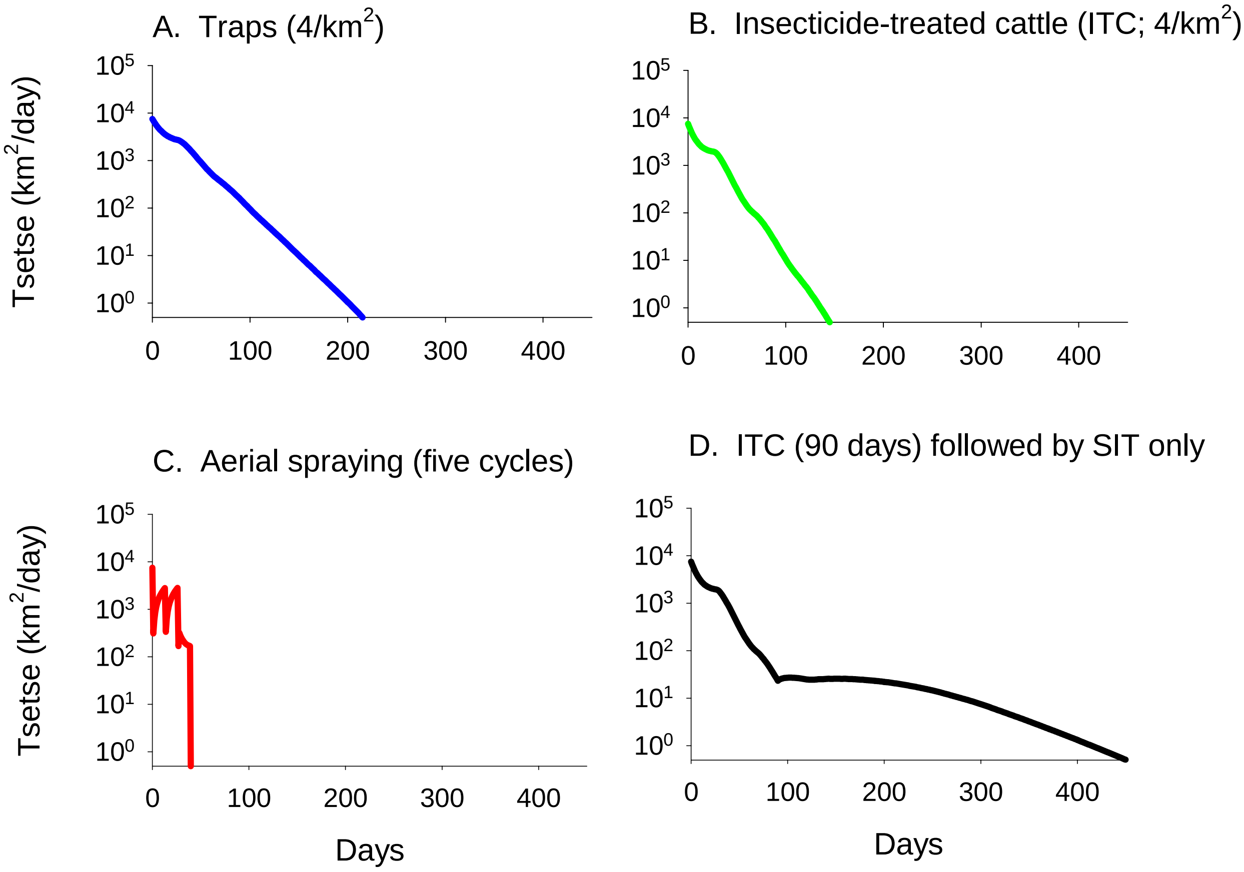
Table 3: *Timings for elimination strategies for isolated tsetse populations.*

Technique	Days required to elimination under ideal conditions[a]	Days deployed in practice[b]	Days monitored
Traps	216	360	720
Insecticide-treated cattle (ITC)	145	360	720
Aerial spraying (SAT)	39	5 cycles (55–85days)	720
ITC suppression (90days) + Sterile insect technique (SIT)	90+361=451	630	720+90=810

Note: [a] As obtained using the tsetse model [b] As used in the calculations which follow.

These modelled results, as illustrated in Figure 5, need to be carefully interpreted. As explained above, they are based on known and generally recognised values for the key biological parameters for tsetse (birth rates and age-specific death rates). The reflect experience obtained in the field (see for example Hargrove, 2003a and b, Hargrove *et al*., 2003, Kgori, *et al*., 2006). They take as their starting point an isolated population where the control technique is effectively deployed and no unforeseen hitches or delays occur – a situation described here as ‘ideal conditions’. Neither the model nor these ‘ideal conditions’ intrinsically favour one technique above another. For example, reared sterile males are assumed to be 75% as viable as wild males, traps are assumed to be deployed without thefts occurring, sufficient candidate cattle for insecticide treatment are assumed to be present throughout the area and aerial spraying takes place at 13 day intervals, with the fly population being decimated by the end of the fourth cycle, with the fifth cycle being added to ensure there are no survivors.

Figure 5: *Outcome of the model runs showing the reduction in isolated tsetse populations achieved by each technique under ideal conditions.*



Source: Outputs obtained from the tsetse population dynamics model which is available from http://www.tsetse.org .

As explained above, having calculated results in an ideal baseline situation, the tsetse model allows for an infinite number of variations to simulate departures from this baseline. In Section 5 below, two of these are examined, the case of a non-isolated tsetse population with invasion pressure from one side and five examples of interrupted operations affecting ITC and SIT. Furthermore, in Section 4, within each control strategy, a number of sensitivity analyses are conducted (different densities of targets and ITC, different costs for flying time and the release of sterile males over different periods).

Other possibilities which could be modelled are the absence or presence of cattle for ITC in some parts of the control area, either seasonally or year round, loss or damage to targets, interruptions to an aerial spray operation, *etc.* By allowing both tsetse and cattle densities km^{-2} to vary throughout the control area, the model can deal with unevenly distributed populations of both cattle and tsetse and thus mimic the clustering of these populations. There is also the possibility of varying tsetse birth and death rates over time and within the treated area. Thus this exercise, in trying to make broad baseline comparisons on which to base costings, only draws on a very limited proportion of the model's capabilities. The model was designed to be able to cope with specific situations with their specific idiosyncrasies.

It should also be noted that even for the baseline calculations, logistical and organisational realities in the field meant that the cost calculations often assumed significantly longer time periods than those obtained from the model runs. Thus the reader should note that in Table 3, the time periods used in practice for each strategy are longer than those specified by the tsetse model.

3.4 The Economic Methodology

Traditionally, the costs cited for each technique have tended to be the field level costs incurred for a year's deployment. The figures quoted in Table 1 are consistent and very specific in that they apply to elimination, but the more generally cited figures in Table 2 tend to blur the distinction between control and eradication and which costs are included and which are excluded from the calculation (see Shaw, 2003, for a discussion of this issue). Given these variations, it is clear that the approach used in an economic[2] analysis needs:

- firstly, to distinguish between work undertaken as part of ongoing tsetse control/ suppression or as part of elimination activities;
- secondly, to include as many of the overheads as possible – especially as these can and do vary between techniques – and ensure that all estimates include the same categories of costs, and
- thirdly, to find a way of dealing with and fully incorporating differences in timing.

In this analysis these factors are dealt with as follows. Firstly, in the context of this study and of its overall objective of helping to inform choice of technique for the forthcoming creation of fly-free zones under the aegis of PATTEC, only elimination is considered. This does not imply that ongoing control activities are not desirable, simply that the objective of this analysis is to look at the creation of long term fly-free zones.

Secondly, the costs include all cost of setting up large scale tsetse control operations – administration, initial surveys and studies and post-control monitoring. The only significant costs omitted from the analysis are the necessary accompanying measures to deal with trypanosomiasis in humans and livestock. An appreciable proportion of cattle carry trypanosomes at any given time. As well carrying those trypanosomes which undermine their own health, they carry those which threaten human health. Cattle thus act as the main reservoir of *rhodesiense* sleeping sickness in the project area, since 18% have been shown to carry human-infective trypanosomes (Fèvre *et al*., 2005). Thus, whatever technique is deployed to deal with tsetse, livestock, particularly cattle, will need to be treated to clear them of their trypanosomes. More importantly, finding and treating people affected by the disease is a humanitarian priority. This is particularly important where the technique chosen takes some time to reduce the tsetse population so that transmission continues after the start of the operation. Even after the operation is complete, in the absence of treatment, infected livestock and people would remain and losses would be incurred. However, essential as these accompanying measures are, they have not been analysed separately here since they apply equally to all tsetse control techniques. Similarly, the estimation of the benefits of dealing with tsetse has also been excluded from this

[2] Another issue of terminology arises here. In this report the word economic is used to cover both wider socio-economic analyses and more narrow financial calculations. The cost calculations are, as in many veterinary and medical studies, a hybrid between economic and financial analyses *sensu stricto* (see Gittinger,1982, for definitions) in that they cover all the costs incurred by the various economic agents affected (public and private sector) but value these costs at current market prices without adjusting for externalities or market distortions.

analysis since its focus is strictly on cost-effectiveness. By dealing with the issues of timing at the cost level, the differences in the point of time from which benefits will be obtained (which reflects the speed with which tsetse can be eliminated) has been to some extent addressed, but of course, not fully dealt with. It is a subject which needs to be addressed in detail in another study.

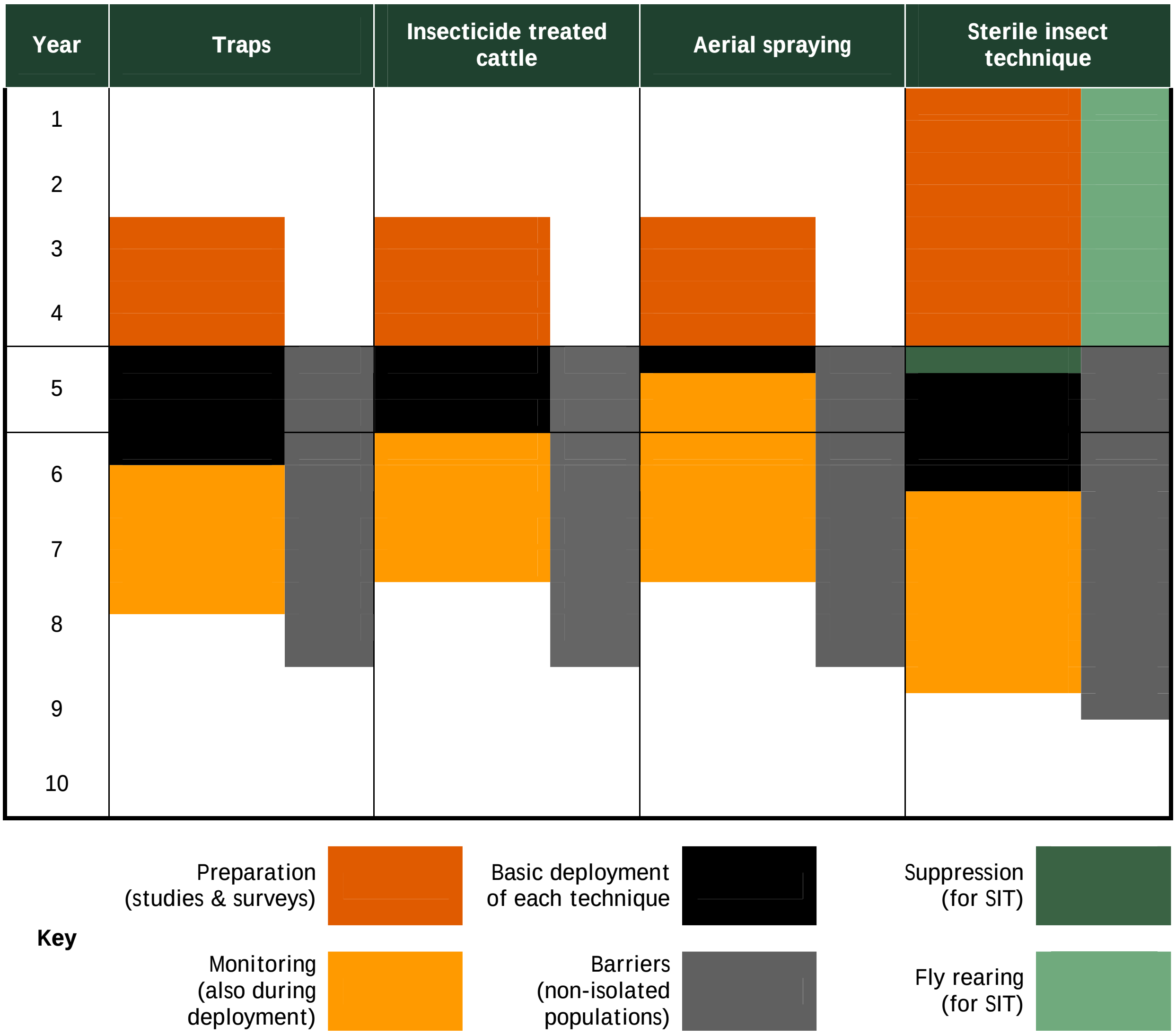
The third issue, timing, has been dealt with rigorously here. The main device used in economic analyses in order to compare sums of money received or disbursed at different points in time is 'discounting' which converts all sums to a value at a selected point in time, a baseline year. This is conventionally selected as the current year, and projected benefits and costs are discounted to their 'present value', so that they are all in today's prices and today's values. For this analysis, however, it was decided that the most appropriate baseline year would be the year in which active tsetse control began in the field. Thus all preparatory costs are incurred prior to this year, then control activities begin, after which monitoring is undertaken. Discounting[3] is analogous to the process of removing compound interest from monies received or disbursed in the future and adding it to those received or disbursed in the past. The discount rate is the interest rate representing the minimum acceptable return on money in the sector for which the project is analysed. In this study, the rate generally used was 10%, a rate normally acceptable for livestock projects. However, in the field of human health, rates of 3%–5% are commonly used. These lower rates reflect the higher value put on human health outcomes and the fact that therefore a lower 'return' is acceptable on such projects. In order to provide a range of values and show how sensitive the calculations are to discounting, results for both 5% and 10% discount rates have been given. The resulting discount factors, as applied in this study, are given in Annex Table A1.

Figure 6 illustrates how the timing works out for each of the techniques analysed. The 'present value' or 'year 0' from the discounting point of view is year 5, when all techniques are deployed in the field. The time needed for each technique to achieve elimination, as given in Table 3, is shaded in black. The 90-day suppression phase, using another technique, needed before deploying sterile males, is shaded in dark green. The lead time varies for each technique, with the longest being required for constructing and establishing colonies of breeding females for producing the sterile males required for SIT (pale green). Other accompanying preparatory measures (principally fly surveys and other studies) are shaded in dark orange. Lastly, the post-elimination monitoring is shaded in pale orange.

The only remaining economic issue is choice of prices. Throughout the calculation all costs were calculated at end 2005 prices for Ugandan public sector activities, based in part on the costs outlined in the PATTEC project proposal (ADB *et al.*, 2004). Following the convention for large projects of this kind, salaries were estimated at 'project' rates which are often significantly higher than normal civil service wages. These constitute an incentive to take part in project and are expected to help ensure the success of the projects. However, this practice both distorts costs and raises issues of motivation and sustainability, as well as inflating costs. For this reason, for local labour, sensitivity analyses were undertaken to look at the effect of using lower wage rates. Farmers' opportunity costs for labour were factored in by including a high overhead for the costs of ITC, the main technique requiring significant investments of farmer's time.

[3] For a detailed explanation of the methods and rationale for discounting see Gittinger (1982), for a discussion of its implications in the context of T & T see Shaw (2003).

Figure 6: *Timings used in the cost calculations for various tsetse elimination techniques (baseline scenario, for trouble-free operations targeting isolated tsetse populations under ideal conditions).*



One other area not explicitly tackled here or included in the costs are environmental side-effects. These fall outside the remit of this particular study. However, readers should be aware that these have been extensively (and expensively) monitored for all the techniques discussed here and it is clear that in the context of elimination activities, the control techniques themselves do not involve adverse side-effects, although this may not hold true where their long term use as barriers to reinvasion is required. Discussion of the environmental impacts of insecticidal methods to control tsetse can be found in Allsopp and Hursey (2004) and Grant (2001) and with specific reference to ITC in Bourn *et al.* (2005) and Vale and Torr (2004). Nor, in the study area, are wide-ranging changes in land use with attendant environmental risks likely to result from the creation of a tsetse-free zone: it is already a densely populated area with a high cattle population.

For ease of interpretation, throughout the costings, the estimates have been made for a 100 x 100 km block of 10,000 km^2, selected to conform with the size of each of the four blocks to be tackled in Uganda's Zone 1 as set out in the PATTEC document (ADB *et al.*, 2004). All costs incurred over the period involved are then converted to their total present value in the year field operations start and then presented as figures km^{-2} freed of tsetse.

4. COST CALCULATIONS

4.1 Overheads and Accompanying Studies

Tsetse control operations in the field need to be supported by an administrative structure and by various accompanying studies before the start of field operations, during the operations and after they have finished. The level of these 'non-field costs' varies greatly according to the type of project, the nature of donor support and donor requirements for activities such as environmental monitoring. Details of these costings are given in Annex Tables A5 and A6.

a) Administration, supervision and other indirect 'non-field' costs and overheads

As was seen in Table 2, there is great variation as to which items are included in 'field' level costs. In this costing exercise, all supervision in the field and an appropriate share of the depreciation on all specialist and generally useable capital items was included in the field costs for each technique, whereas the cost of maintaining and staffing a headquarters office was calculated separately under the heading of 'administrative costs'. This cost was based on the estimates in ADB *et al*., 2004. These included provisions for running a project coordination office, for support to COCTU, for support to Uganda Trypanosomiasis Control Council (UTTC), for local meetings, for attendance at international meetings, for an annual review, and for provision of training and expert services. Over the ten years analysed, after discounting at 10% and adjusting for the size of the project area (calculated for a single 10,000 km^2 block in this analysis as against the 40,000 km^2 provided for in ADB *et al*. (2004)) this cost came to a total of US$ 30 km^{-2} for control using traps, ITC or SAT (Annex Table A5) and accounts for 14% of non-field costs. For SIT, due to the longer lead time, the cost was higher, at US$ 47 km^{-2} (Annex Table A6) or 19% of non-field costs.

b) Entomological Surveys and monitoring

Before any tsetse control operation can begin, surveys are required to confirm which flies are present in the area and their distribution. The ADB *et al*. (2004) document provides for the development of land cover and vegetation maps followed by surveys using traps deployed by 5 field teams based on sampling of selected 1 – 5 km^2 blocks in the rainy and dry season, the cost of these would work out at US$ 42 km^{-2} of the area freed of tsetse, after discounting at 10% (Tables A5 and A6). This figure also includes a provision for investigating tsetse population genetics. Once operations are underway, monitoring during the control activities and after they have been completed would be required, after discounting at 10% this cost would come to US$ 82 km^{-2} if traps, ITC or SAT were used to eliminate tsetse, and US$ 91 km^{-2} if SIT were used, being slightly higher due to the longer period taken by the control operation. The entomological surveys and monitoring would thus account for just over half of non-field costs (56-58%).

c) Other accompanying feasibility studies and monitoring

The other accompanying studies usually proposed alongside large scale tsetse control activities are socio-economic, environmental and disease surveys. Provision for all of these was included in ADB *et al.* (2004):

- **socio-economic studies**: in this case a survey covering 8,000 households undertaken over two months was proposed;
- **environmental monitoring:** surveys and monitoring to be undertaken in a sample of representative ecozones, covering both the usage of insecticide and monitoring of land use after tsetse control;
- **animal trypanosomiasis surveys:** on a sample of animals using standard parasitological (buffy coat and MHCT) and serological screening (Ab_ELISA) techniques together with treatment of animals found to be trypanosomiasis positive; and
- **sleeping sickness survey:** cost of a standard survey and drugs for treatment of patients is included.

The cost of these surveys and studies came to US$ 60 km^{-2} after discounting at 10%, or just over a quarter of non-field costs (25% - 28%, see Annex Tables A5 and A6).

However, as discussed above, appropriate disease control activities for people and livestock need to be undertaken in tandem with the tsetse control work. This is particularly crucial in the project area because of the importance of the cattle reservoir for *T. b. rhodesiense*, the cause of sleeping sickness. Furthermore, a substantial body of work in this area has confirmed that the standard microscopy survey techniques underestimate the true prevalence of trypanosomiasis in cattle as compared to what the more sensitive PCR technique would reveal (Picozzi *et al.*, 2002). Thus the results of field trypanosomiasis surveys would need to be interpreted as indicative of areas where the disease was a problem but not always of its magnitude. Substantial extra funds would need to be allocated to treating cattle against the disease and it may prove more cost-effective to block treat the cattle population than to undertake expensive tests to determine which animals are infected.

Thus the total non-field costs come to US$ 30 for administration plus US$ 184 for entomological and other studies for traps, ITC or SAT and US$ 47 for administration plus US$ 194 for studies for SIT.

4.2 Traps

Turning next to the basic cost of deploying each technique to the point where elimination is achieved, the details of the costings for traps are given in Annex Table A2 and the results are summarised in Tables 4 and 5.

Table 4: *Summary of cost calculations for trap deployment and servicing for one year.*

Traps km^{-2}	Number of teams required	Undiscounted cost km^{-2} (US$)
4	10	176
4	15	229
4 low cost	10	158
4 low cost	15	202
8	20	352
8	30	458
10	25	441
10	38	572
20	50	881
20	75	1145

Note: Underlying assumptions for calculating the number of teams required were that teams could deploy some new 500 targets a month, and service 750. Initial deployment was allowed to take some 6 months, so that one team could deploy 3,000 targets. Thereafter one third of the teams would be disbanded and for elimination targets would be serviced on two subsequent occasions and then left in the field. For barriers, however, the higher number of teams would need to be maintained, since targets would need to be replaced annually. For details see Annex Table A2.

Traps, rather than targets, are considered appropriate for use against *G. fuscipes*. They were used in this area deployed at 10 km^{-2}, where they achieved local reductions of 99% in tsetse populations (Lancien, 1991, Lancien and Obayi, 1993). Used with odour baits against *morsitans* group flies at a density of 4 km^{-2}, they are able to eliminate these fly populations. Thus the costs at trap densities ranging from 4 km^{-2} to 20 km^{-2} were calculated here, to allow for a range of values and for using twice as many traps km^{-2} in barriers as were required for elimination. Table 4 shows the range of costs obtained, for a year of operation, and explains the assumptions about manpower and trap deployment used.

The trap deployment was costed as being undertaken by teams, who would gradually set out traps throughout the area over a period of six months, then return twice within the tsetse elimination operation to service the traps. Table 5 shows the costs for the eighteen months required: 6 months to completely deploy all traps, then a further year for the traps to remain in the field, so as to fall well within the period of 216 days which the tsetse model (Table 3) judged necessary to eliminate tsetse. A lower cost option using local labour and fewer vehicles for supervisors was also costed (see Table A2 addendum). After discounting at 10%, the costs ranged from US$ 251 for low cost trapping at 4 km^{-2} to deal with *morsitans* group flies such as *G. pallidipes* to US$ 706 for deploying traps against *G. fuscipes* at 10 km^{-2}. In terms of logistics and organisation, traps are the most demanding of the techniques examined.

Table 5: *Summary of cost calculations for tsetse elimination in an isolated area using traps.*

Year	Traps at 4 km^{-2}	Low cost traps at 4 km^{-2}	Traps at 8 km^{-2}	Traps at 10 km^{-2}	Discount rate
1	0	0	0	0	No discount
2	0	0	0	0	
3	0	0	0	0	
4	0	0	0	0	
5	203	180	405	506	
6	88	79	176	220	
7	0	0	0	0	
8	0	0	0	0	
9	0	0	0	0	
10	0	0	0	0	
Cost km^{-2} tsetse-free	291	258	581	726	0%: no discount
Cost km^{-2} tsetse-free	287	254	568	716	5%
Cost km^{-2} tsetse-free	283	251	565	706	10%

Note: For each trap density, the larger number of teams are deployed for the first six months while the traps are placed, thereafter the smaller number of teams work for a year. Please note that all figures were rounded to the nearest US$ 1 so that not all figures are in exact linear progressions.

4.3 Insecticide-treated Cattle (ITC)

The costs of ITC were derived from those given in Vale and Torr (2005) and Bourn *et al.* (2005) and are set out and explained in Table 6. The costs vary considerably depending on how the insecticide is applied. The traditional pour-on formulation is the most expensive, at US$ 22 per animal treated per year. Spraying is far more cost-effective, costing US$ 7 per animal per year. Lastly, applying insecticide restrictively only to the animal's legs and belly (see Bourn *et al*., 2005) allows for a considerable saving, reducing the cost to $ 1.5 per animal per year. Although the tsetse model (Table 3) predicts that ITC would eliminate tsetse in 145 days, ITC is maintained for a year in these calculations. All the costs are linear so that, at 4 ITC km^{-2}, the cost of spraying is US$ 28, and at 8 km^{-2}, it is US$ 56. All costs are incurred in year 5, so that the discount factor is 1 (Annex Table A1) and thus no adjustment is needed.

Table 6: *Basis for cost calculations for insecticide-treated cattle.*

Cost (US$)	Per animal treated /year	Treating 4 cattle km^{-2}	Treating 8 cattle km^{-2}
Alphacypermethrin spray[a]	7.0	28	56
Alphacypermethrin spray, restricted application[b]	1.5	6	12
Traditional pour-on (Spot-on)[c]	22.5	90	180

Notes:

[a] Alphacypermethrin spray costs based on those calculated in Bourn *et al*., 2005. These in turn were derived from calculations in Vale and Torr, 2005 and include a very generous allowance for application overheads (90% of the total cost).

[b] Restricted application refers to the spraying of the legs and belly only.

[c] Spot-on cost based on 1 ml per 10 kg liveweight, 200 ml therefore treats 2,000 kg, or 8 largish animals. Cost US$ 7.50 for 200 ml, so cost per animal US$ 0.94 and cost per annum for twelve treatments with a 100% overhead for veterinary and/or administration costs is US$ 22.50.

4.4 Aerial Spraying (SAT)

The details of how the costs for SAT were calculated are given in Annex Table A3. These costs came to US$ 380 km^{-2}, of which the bulk (US$ 350) was for insecticide and flying time the remainder being for staff, supervision, rehabilitation of the airport and droplet monitoring. As costs are only incurred in year 5 (see Table 7) when tsetse control operations are undertaken in the field, there is no effect from discounting. It should perhaps be noted that aerial spraying is the strategy which was costed out in least detail, with costs calibrated in line with those of the recent operations in Botswana. More work is needed to improve on these costings.

Table 7: *Summary of cost calculations for tsetse elimination in an isolated area using aerial spraying.*

Year	Aerial spraying 5 cycles (US$)	Discount rate
1 - 4	0	No discount
5	380	
6 – 10	0	
Cost km^{-2} tsetse-free	380	0%, 5% or 10% discount rate

4.5 Sterile Insect Technique (SIT)

The components of the costs of SIT are set out in detail in Annex Table A4, and the costs for the 10,000 km^2 block are calculated in Table 8 below. As was the case for traps, because the technique involves a set up phase and a deployment phase, carefully working out the timing and applying discount factors was important. The cost km^{-2} of releasing sterile males works out at US$ 758 when discounted at 10%. Because SIT work spans the longest period and many of the costs are incurred before the actual tsetse control operations start in year 5, the costs of SIT are affected by discounting to a greater extent than those of the other strategies.

Table 8: *Summary of cost calculations for the breeding and release of sterile males in an isolated area.*

Year	Fly rearing US$			Fly release US$	Totals US$	Discount rate
	Capital items	Recurrent items	% Share for project			
1	7,760,400	835,600	25	0	2,149,000	
2		835,600	25		208,900	
3		835,600	25		208,900	
4	32,000	835,600	25		216,900	
5		835,600	100	1,233,500	2,069,100	No discount
6	211,000	835,600	50	1,233,500	1,756,800	
7						
8						
9						
10						
Cost for 10,000 km^2					6,609,600	0%: no discount
Cost km^{-2} tsetse-free					661	0%: no discount
Cost km^{-2} tsetse-free					705	5%
Cost km^{-2} tsetse-free					758	10%

Note: Figures extracted from ADB *et al*. (2004) with some adaptations. Basis for calculations can be found in Annex Table A3 and the source of these figures is explained in a footnote. It should be noted that for this control strategy, with most of the costs occurring before year 5, this being the year to which figures are discounted, discounting costs increases their relative weight, so that at higher discount rates the cost km^{-2} increases.

SIT is also very sensitive to the cost of flying time. Table 9 shows the results of a series of sensitivity analyses of the SIT costs, all designed to reduce the cost, either by reducing the cost of flying time or the period over which sterile flies are released. These assumptions would have to be checked against field conditions. For example, although ADB *et al.* (2004) allowed for 18 months of fly releases, the tsetse model predicts that if sterile males are as nearly as viable as wild males, only 12 months would be needed.

Table 9: *Sensitivity analyses on the cost of SIT.*

Year	Cost of flying time US$ 700 per hour, release over 18 months	Cost of flying time US$ 700 per hour, release over 12 months	Cost of flying time US$ 500 per hour, release over 18 months	Discount rate
US$ km^{-2} tsetse-free	661	579	591	0%: no discount
US$ km^{-2} tsetse-free	705	627	637	5%
US$ km^{-2} tsetse-free	758	683	691	10%

4.6 Cost Comparisons – Composite Table

Having calculated the cost of each method individually and estimated the non-field costs, all the costs need to be combined to provide realistic estimates of the total cost km^{-2} of each whole operation. Table 10 and Figure 7 summarise these. For operations involving traps and ITC, a number of different estimates for the field cost are included, reflecting different trap densities, different ITC densities and different methods of applying the insecticide to cattle. For SAT the basic cost of US$ 380 km^{-2} is used. For SIT the calculation is slightly more complex, since prior suppression is required. Therefore the basic cost of adding SIT (US$ 758) is initially listed, then the total field costs, once the cost of suppression using either SIT or ITC has been factored in, are given.

The field costs show a very great range, with the various ITC options being far cheaper (range US$ 12 – 180 km^{-2}) than all other methods. These are followed by traps used against savannah species deployed at 4 km^{-2} (US$ 251 - 283), then SAT at US$ 380 km^{-2}, followed by 10 traps km^{-2} against *G. fuscipes* (US$ 706). SIT is envisaged as being undertaken where other techniques cannot completely remove the fly population. In these circumstances its cost, following suppression using another technique, thus becomes the highest (US$ 758 to add SIT, rising up to US$ 1,062 when the cost of suppression using SAT is added).

To the field costs must be added the costs of administration and the various studies, as described in Section 4.1 above. These costs (US$ 30 for administration plus US$ 184 for studies for traps, ITC or SAT and US$ 47 for administration plus for US$ 194 for studies for SIT) add considerably to the field costs, accounting for half or more of the total costs km^{-2} for ITC, and nearly half for traps for savannah flies. Accordingly, for some methods, a sensitivity analysis involving reducing the costs of the studies by 50% was undertaken.

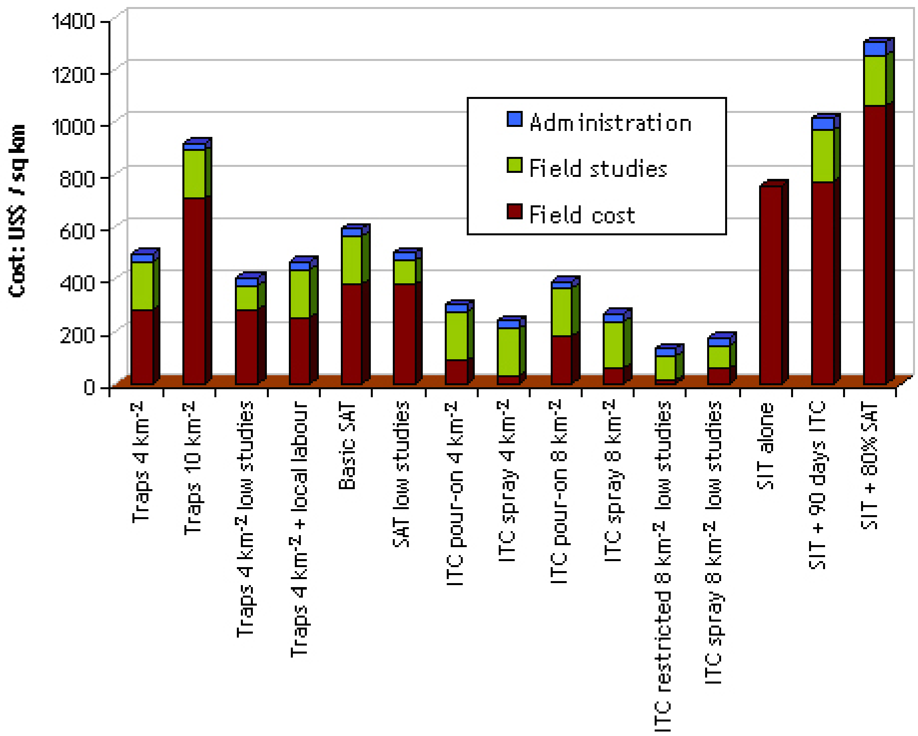
Total costs for elimination thus maintain the ranking given above as well as the absolute differentials, but with the addition of the non-field costs, these range from US$ 130 to US$ 1,300.

Table 10: *Summary table for cost of creating a tsetse-free zone for isolated tsetse populations under ideal conditions (see also Figure 7).*

US$ km^{-2} (discounted at 10%)	Field cost	Studies	Admin	Total
Traps				
Savannah tsetse species (4 km^{-2})	283	184	30	497
G. fuscipes (10 km^{-2})	706	184	30	920
Savannah + fewer studies	283	92	30	405
Savannah tsetse species + local labour	251	184	30	465
SAT				
Basic SAT	380	184	30	594
SAT + fewer studies	380	92	30	502
ITC				
Pour-on (4 km^{-2})	90	184	30	304
Spray (4 km^{-2})	28	184	30	242
Pour-on (8 km^{-2})	180	184	30	394
Spray (8 km^{-2})	56	184	30	270
Restricted (8 km^{-2} and fewer studies)	12	92	30	134
Spray (8 km^{-2} + fewer studies)	56	92	30	178
SIT				
Addition of SIT alone	758			758
SIT + 90 days ITC	772	194	47	1013
SIT + 80% SAT	1062	194	47	1303

Note: For SIT suppression using SAT calculated is at 80% of cost of spraying = US$ 354 (4 instead of 5 cycles) although, once the infrastructure is in place it would make more sense to spray the full 5 cycles required for elimination, or as the cost of 90 days sprayed ITC at 8 km^{-2} = 56/4 = US$ 14.

Figure 7: *Graph showing cost breakdown by tsetse control method (creation of a tsetse-free zone for isolated tsetse populations under ideal conditions).*



Source: Table 10

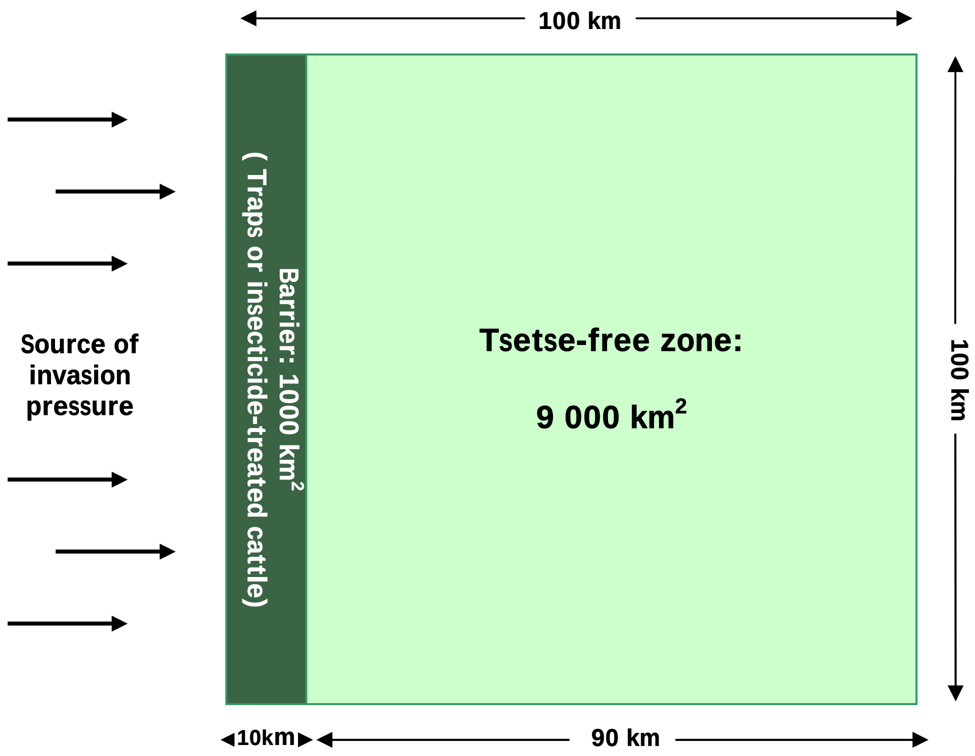
5. SENSITIVITY ANALYSES

In addition to the sensitivity analyses specific to each strategy (*e.g.* looking at different methods of applying insecticide to cattle or at different prices for key cost components such as flying time or local labour) the effect of dealing with non-isolated populations was examined and the effect of interruptions in the control work was modelled.

5.1 Non-isolated Populations

As can be seen from Figures 1 - 3, current information on the distribution of tsetse in Uganda indicates that there are *G. fuscipes* and possibly some isolated pockets of *G. pallidipes* in the northwest of Zone 1 in the vicinity of Lake Kyoga as well as in south-eastern Uganda along the Kenya border (Magona *et al*., 2005 and Waiswa *et al*., 2006); similarly both flies are known to be found in southwestern Kenya in the area bordering Zone 1. Thus a tsetse control operation in that area would face reinvasion pressure, probably from two fronts. If, as is currently planned, operations take place in Kenya at the same time as in Uganda, reinvasion pressure would mainly be from the northwest.

Figure 8: *Layout of area under invasion pressure from one side: basis for calculations of cost of maintaining a fly-free zone for a non isolated tsetse population.*



In order to calculate the effects of this on costs, the tsetse model was set up to investigate dealing with a situation, as illustrated in Figure 8, where there is invasion pressure on one side of the 10,000 km^2 block. Initially the situation without a barrier was modelled. After one year of deployment of each technique traps and ITC would maintain 90% of the area fly-free, despite reinvasion after 5 cycles of SAT 73% of the area would remain fly free, but suppression plus SIT would not succeed in eliminating the fly. Thereafter, the more realistic situation of the creation of a fly-free zone protected from reinvasion by a barrier as illustrated in Figure 8 was modelled. In this situation, a 10 km wide barrier of either traps or ITC was modelled and was assumed to be successful in maintaining the remaining 9,000 km^2 free of tsetse. The nature and viability of such barriers still needs further study, accordingly a range of densities of ITC and traps were costed.

Table 11: *Basis for cost calculations for barriers.*

Year	US$ km^{-2} Insecticide-treated cattle at 8 km^{-2} used as a barrier with:				US$ km^{-2} Traps at 8 km^{-2} used as a barrier with:				Discount rate
	ITC[a] at 4 km^{-2}	RA[b] at 8 km^{-2}	SAT[c]	SIT[d]	Traps[e] at 4 km^{-2}	Low cost traps[f] at 4 km^{-2}	SAT[g]	SIT[h]	
1	0	0	0	0	0	0	0	0	No discount
2	0	0	0	0	0	0	0	0	
3	0	0	0	0	0	0	0	0	
4	0	0	0	0	0	0	0	0	
5	28	56	56	56	282	246	458	458	
6	56	56	56	56	458	404	458	458	
7	56	56	56	56	458	404	458	458	
8	56	56	56	56	458	404	458	458	
9	0	0	0	56	229	202	0	458	
10	0	0	0	0	0	0	0	0	
Cost km^{-2} of barrier	196	224	224	280	1885	1660	1832	2290	0%: no discount
Cost km^{-2} tsetse-free	22	25	25	31	209	184	203	254	
Cost km^{-2} of barrier	181	209	209	255	1717	1513	1705	2082	5%
Cost km^{-2} tsetse-free	20	23	23	28	191	168	189	231	
Cost km^{-2} of barrier	167	195	195	234	1577	1389	1597	1910	10%
Cost km^{-2} tsetse-free	19	22	22	26	175	154	177	212	

Notes: Conversion from cost km^{-2} of barrier to cost km^{-2} tsetse-free is as illustrated in Figure 8, on the basis that for 9,000 km^2 tsetse-free, a 1,000 km^2 barrier is required.

[a] For ITC at 4 km^{-2}, during the year of deployment in the barrier area an additional 4 cattle km^{-2} need to be treated, thereafter 8 cattle km^{-2} are treated.

[b] For restricted application (RA), the barrier is assumed to consist of an extra 8 cattle km^{-2} being treated in the barrier area both during the initial tsetse control phase and the three years thereafter.

[c] For SAT, the full barrier needs to be in place when the operation starts, throughout the control phase and for three years thereafter.

[d] The ITC are required for an extra year because control using suppression + SIT requires an additional 9 months of activities (Table 3). One year's additional ITC is costed, if it were needed for only 9 months the barrier cost would fall by $1 km^{-2} of tsetse-free land.

[e] This trap barrier and trap deployment are suitable for savannah flies only. The costs in the first year are lower, as an only additional 4 traps km^{-2} need to be added in the barrier area to the traps already deployed for control. However, since the area treated is much smaller and it is essential to remove old traps and replace them with new ones, a slightly larger labour force is maintained throughout, with 3 standard trap teams working full time to maintain and replace 8,000 traps.

[f] These illustrate the same strategy as for 'e' but with the lower cost trapping strategy, using fewer vehicles and local labour.

[g] Again, this trap barrier is suitable for savannah flies only. It is required for an extra year since control using suppression plus SIT takes longer.

From the cost point of view, this worked out as follows. The tsetse free zone was considered to be the 9,000 km^2, so the total cost of the initial tsetse elimination plus the maintenance of the barrier were added up and then divided by 9,000 to obtain the cost km^{-2} freed of tsetse. In these calculations the barrier was assumed to be maintained for just 3 years. Obviously, unless further tsetse clearance activities extended the tsetse free zone within this time frame, a longer period would be necessary. The assumptions used for each strategy are explained in detail in the footnotes to Table 11. The cost for the barriers varies greatly depending on whether traps or ITC are used, the former being far more costly. Smaller variations reflect the extent to which the barrier complements the technique already being used and differences in the assumptions about how insecticide is applied to the cattle and at what density the ITC are deployed.

Table 12: *Summary cost table for non-isolated tsetse populations subject to invasion pressure from one side.*

$ km^{-2} (discounted at 10%)	Field Cost	Barriers	Studies	Admin	Total	Ratio[a] NI/IS
Traps + ITC or trap barrier						
Savannah tsetse species (4 km^{-2}) + trap barrier (8 km^{-2})	314	175	224	43	757	1.52
G. fuscipes (10 km^{-2}) + sprayed ITC barrier (8 km^{-2})	784	22	224	43	1074	1.17
Savannah (4 km^{-2}) + trap barrier (8 km^{-2}) + fewer studies	314	175	112	43	645	1.59
Savannah (4 km^{-2}) + trap barrier (8 km^{-2}) + local labour	279	154	224	43	700	1.51
SAT + ITC or trap barrier						
Basic SAT + trap barrier (8 km^{-2})	422	177	224	43	867	1.46
Basic SAT + sprayed ITC barrier (8 km^{-2})	422	22	224	43	712	1.20
Basic SAT + sprayed ITC barrier (8 km^{-2})+ fewer studies	422	22	112	43	599	1.19
ITC + ITC barrier						
Pour-on (4 km^{-2}) + ITC barrier (8 km^{-2})	100	19	224	43	386	1.27
Spray (4 km^{-2}) + ITC barrier (8 km^{-2})	31	19	224	43	317	1.31
Pour-on (8 km^{-2}) + ITC barrier (16 km^{-2})	200	38	224	43	505	1.28
Spray (8 km^{-2}) + ITC barrier (16 km^{-2})	62	38	224	43	368	1.36
Restricted (8 km^{-2}) + ITC barrier (8 km^{-2})	13	22	112	43	191	1.42
Spray + ITC barrier (8 km^{-2}) + fewer studies)	62	38	112	43	256	1.44
SIT + ITC or trap barrier						
SIT + ITC suppression + ITC barrier + ITC barrier (8 km^{-2})	842	26	234	0	1102	1.45
SIT + SAT suppression + trap barrier (8 km^{-2})	858	212	234	68	1372	1.35
SIT + SAT suppression + ITC barrier + ITC barrier (8 km^{-2})	1180	26	234	68	1508	1.16

Note: Administrative overheads and studies have been adjusted respectively to account for the extra cost of supervising maintenance of the barriers and longer period of entomological monitoring required.

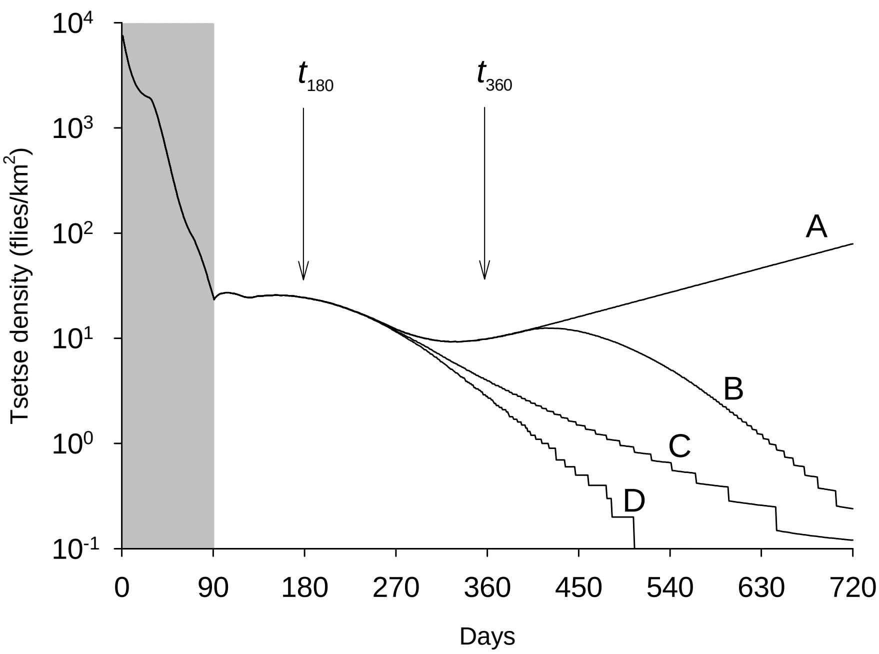
[a] Ratio NI/IS refers to the ratio of the cost for a non-isolated (NI) area as costed here to an isolated area (IS) as costed in Table 10.

Table 12 is laid out in the same way as Table 10 and shows how these costs work out for each strategy for non-isolated populations. Where an ITC barrier is used, this increases the cost km^{-2} freed of tsetse by 15 – 20%; where traps are used the cost increases by 30 – 60%.

5.2 Modelling Adverse Events – Trouble Shooting

Lastly, the tsetse model was used to examine how robust the techniques were to interruptions in the work. Figure 9 shows what would happen if, after a successful suppression phase, there were interruptions in the release of sterile males. The base-line scenario was a trouble-free operation (D). If sterile male releases ceased after 90 days (A), the tsetse population would gradually recover, however, if releases were resumed by day 360 (B) the tsetse population would again decline as it would if after 180 days there was a reduction in the number of sterile males released from 3 per wild male to only 1 per wild male (C). Thus SIT is shown to be reasonably robust to adverse events.

Figure 9: *Effects of sporadic failure in the release of sterile males.*

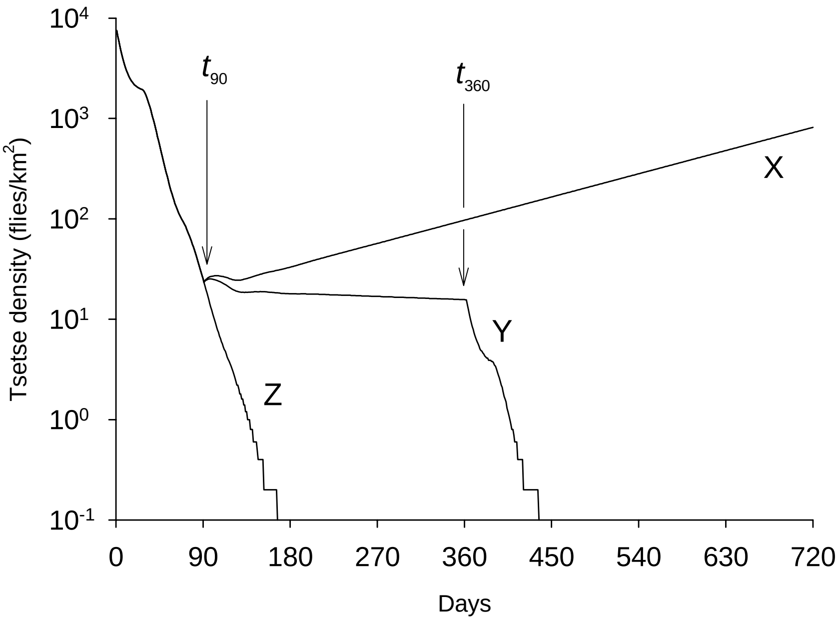


Note: Density of tsetse if a 90 day suppression phase with SIT (grey area) is followed by just 90 days of SIT (line A), or the resumption of releases at 360 days (B) or a low (1:1) release rate after 180 days (C) or a trouble-free operation (D).

A similar analysis was undertaken for ITC (Figure 10). Two scenarios were compared to the baseline of a trouble-free operation (Z). If ITC stopped after 90 days (X) the tsetse population would begin to recover as it did in scenario A for SIT, where tsetse control ceased after 180 days (90 of suppression plus 90 of SIT). If there were a marked reduction in the kill rate of tsetse between days 90 and 270, due to, say, failure to treat sufficient cattle or the limited availability of the insecticide, the tsetse population would stabilise at a lower level and decline slightly during the period of limited operation of ITC and then, if ITC were resumed at the correct level, would resume its rapid decline toward elimination.

Thus both SIT and ITC show a good ability to recover from setbacks.

Figure 10: *Effects of sporadic failure in the treatment of cattle.*



Note: Density of tsetse if ITC is applied for 90 days only (X), or killing rate declines from 12% to 1% between 90 and 270 days and then returns to 12% (Y) or a trouble-free operation (Z).

These analyses thus show how the technologies' costs are affected by the very likely scenario of having to deal with non-isolated populations and how interruptions and sub-optimal functioning can delay the reduction in tsetse populations. As discussed in Section 3.3, these represent only two of the many departures from 'ideal conditions' which the tsetse model could be used to simulate.

6. DISCUSSION

The marked differences in costs for different tsetse control techniques resulting from the analyses presented in Tables 10 and 11 strongly reinforce the argument for very careful choice of technique for the creation of tsetse-free areas. However, as has been much discussed in the field of tsetse control, there are factors other than simple economic cost which could influence choice of technique. Some generally agreed guidelines can be found in Mattioli *et al*. (2004). In theory economic cost calculations should incorporate all these other factors, in practice this is difficult to do, either because there are areas of uncertainty or because valuing some side-effects and impacts is difficult. For this reason, the main non-financial factors and their relevance to the costs calculations undertaken are discussed below. This discussion points to a number of areas where there are gaps in the knowledge needed to underpin the cost calculations.

6.1 Environmental Considerations

Environmental issues have been hotly debated in this context. It is important to distinguish between (i) the direct side-effects which are attributed to controlling tsetse using particular techniques, especially those which rely on insecticides and (ii) the long-term effects relating to changes in land cover, land use and changes in farming practices, such as increased use of work oxen and higher livestock populations that would be expected to come about as a result of tsetse control. As explained in Section 3.4 above, a discussion of the environmental issues falls outside the remit of this study. Extensive monitoring of all insecticidal techniques has been undertaken (see Allsop and Hursey, 2004) and they have been exonerated of having any long term environmental effects. The issue of changes in land use following tsetse control remains important, although in the present study area, with its dense human and livestock populations, this is probably less relevant. In the target area in Uganda, it is likely that the benefits of tsetse control will lead to a reduction in livestock losses and the removal of HAT, rather than to a substantial change in land use and production patterns. In other parts of Africa, it is possible that tsetse control will only accelerate pre-existing patterns of land use change (Swallow, 2000) or may even be consolidated or accelerated by land use changes resulting from expanding human populations (Bourn *et al*., 2001). For PATTEC, however, given the long term commitment to tsetse eradication underwritten by Africa's leaders, the land use issue is an important one and, in the short term should help to dictate which areas are chosen as priority areas for the creation of tsetse-free zones. Nevertheless, it should be noted that the post-tsetse clearance land use consideration is largely independent of choice of technique, except in so far as the initial choice of technique reflects current land use – for example due to the nature of the vegetation cover and terrain or the fact that ITC cannot be used where there are no cattle.

Overall, environmental considerations should only affect choice of technique where clear evidence exists that in a specific area one technique rather than another should be rejected or preferred on the basis of environmental considerations alone.

6.2 Technical Considerations

Technical effectiveness – if the objective is to eliminate, whether the selected technique can actually eliminate the tsetse species present in a given area – is obviously the main criterion for choice of technique. The economic calculations made in this paper are underpinned by the results of the tsetse population model based on the best available data about the performance of each technique. It is strongly suggested that this sort of modelling approach be retained as an important tool in planning tsetse control operations. As more schemes are undertaken and more data become available, the model can be further validated against field situations and the factors responsible for divergence from the results under ideal conditions can be quantified in different contexts.

Each of the tsetse control techniques has strengths and weaknesses, which are well known and described in the literature and a detailed discussion is outside the scope of this paper (the reader is referred to the papers in Maudlin *et al*., 2004 for more information). Thus, traps and targets are vulnerable to theft and require a high degree of community awareness and involvement to support their continued deployment. ITC depends on treating large animals (cows, bulls or oxen) and so, given local herd compositions, requires a cattle density about 2.5 times greater than the number of animals to be treated km^{-2}. SAT is difficult to apply in broken or rugged terrain and higher insecticide doses are needed to deal with larger flies, such as *G. pallidipes* and SIT has so far only been used to deal with one tsetse species at a time. The techniques analysed in this paper can be used both for elimination and for ongoing control of tsetse populations. However, the use of SIT against tsetse has always been considered exclusively in an elimination context, to deal with residual fly populations remaining after suppression using another method. SIT is also considered to be the technique of choice only where other techniques are unlikely to be able to completely eliminate the tsetse population. Because of the long lead time in breeding sterile flies, the need to be able to predict where SIT will need to be deployed and on what scale, reinforces the need to have a clear idea of how effective the other techniques are likely to be. Thus, aside from the economic considerations, the debate which we must all engage in is defining which circumstances favour which technique, where combinations of techniques are appropriate and where some techniques are unsuitable.

However, despite the fact that tsetse control has been undertaken over some half a million km^2 of Africa's tsetse-infested lands (Allsopp and Hursey, 2004), the only areas that have remained fly free are the 200,000 km^2 of northern Nigeria cleared by ground-spraying and helped to be maintained fly free by high human population densities and associated settlement of riverine areas (Davies, 1964 and 1971); in the 1990s the 40,000 km^2 of northern Zimbabwe cleared by a combination of ground-spraying, targets and SAT (Torr *et al*., 2005), and the 1,600 km^2 of Unguja Island cleared by SIT, as well as, hopefully, the 16,000 km^2 of Botswana's Okavango delta recently controlled using SAT (Kgori *et al*., 2006). The history of tsetse clearance work in many countries has been one of trying to maintain fly free areas and resist reinvasion, in the face of changing – usually dwindling – financial support and logistical difficulties.

In the project area addressed by this paper, there are some specific uncertainties with respect to the performance of particular techniques, which need to be weighed up when interpreting the cost calculations.

- Although trapping with 10 traps km^{-2} was successful in reducing the populations of *G. fuscipes* by 99% during operations in the 1990s (Lancien, 1991; Lancien and Obayi, 1993) this control effort targeted a non-isolated tsetse population with the objective of reducing the incidence of HAT, not of eliminating tsetse. The rapidity of the population reduction is such that it is likely that ongoing operations in an area protected from reinvasion would lead to elimination. However, an unpublished trial undertaken at the time, which compared the use of traps, of traps plus ITC and a control area showed that the reduction in fly populations was most rapid where ITC were used alongside traps (personal communication L. Semakula). As ITC on their own were not included in the trial it is not possible to determine whether it was the association of traps and ITC that was so successful or the ITC component in its own right. In any case, for *G. fuscipes*, the high trap density required made this approach very costly (the second most expensive, after SIT), so that while justified as a means of interrupting transmission and lowering the incidence of HAT, based on current scientific knowledge, it would not be the first choice for creating a large fly free zone in a *G. fuscipes* area, on economic grounds. Furthermore, the logistics of deploying such a large number of traps, needing at least 30 field teams, mean that organising it may be impractical.

- Returning to ITC, there is a need to test their effectiveness on a large scale in the project area. Trials are already being undertaken to the north of the project area and results will shortly be available (personal communication, Sue Welburn). Some of the issues involved have been discussed in Welburn *et al*., 2006. In particular, because it is so attractive financially, since it minimises the use of insecticide and reduces the tick burden without compromising endemic stability (the cattle population's underlying resistance to tick-borne diseases) the efficacy of the restricted application approach on a large scale needs to be further tested. The strengths and limitations of ITC have been analysed in Hargrove *et al.* (2003) with reference to actual field operations.
- Although the project area is densely populated (nearly 250 people km^{-2} and 40 cattle km^{-2}) there are some areas near the shore of Lake Victoria as well as some islands where it is thought that the techniques analysed would not work and thermal fogging might need to be used, as discussed in ADB *et al*., 2004. This needs to be further investigated.
- The distribution and abundance of *G. pallidipes* in the area has important implications, in particular for the use of SIT since it would eventually need to deal with two species. This would require rearing two fly species and either two release operations or releasing two species of sterile males simultaneously. The costs presented here for SIT refer are based on ADB *et al*., 2004, and refer to dealing with *G. fuscipes* only. For the other techniques, the costs are applicable to an infestation with two species.

6.3 Funding Sources

The availability and cost of funding for each technique is a major component of the decision-making process. A number of factors need to be considered.

- Who will fund the work? Where country governments have to fund the elimination work, either through currently available funds or through loans, it can be argued that more stringent criteria may apply (so that more cost-effective techniques need to be chosen) since the competing demands on these funds are so high and debt reduction is, in itself, an important government objective. If donor funding is available, then the preferences of individual donors and competing needs for funds from individual donors need to be considered. Lastly, if there are opportunities for cost-sharing, especially with the ultimate beneficiaries of the work, this has an impact on the level of investment that country government can commit to as well as to the type of technique chosen. Funding by the beneficiaries may often be in terms of time rather than cash (*e.g.* Kamuanga *et al*., 2001) in which case it will tend to be tied to particular techniques (*e.g.* supervising traps, treating cattle with insecticide). Their resources and ability to sustain this investment also need to be considered.
- Is funding tied to particular techniques? If grant funds are available for one control approach or for work in a particular region, then it may makes sense to take this up. However, most projects do require an input of local resources, if only of skilled staff, so that the correct basis for economic decision-making would be, as always, so select the approach which offers best value for the money actually spent by the decision-maker as compared to the next best alternatives.

6.4 Organisational Considerations

Another factor which has been debated is whether what could be termed 'high technology approaches' (basically SAT and SIT), which involve limited on-the-ground participation and a less complex organisational structure, are therefore more effective than other approaches (targets, traps and ITC), which require much more supervision and involvement of local communities. It has often been stated that the failure of some tsetse control programmes has been due to a lack of sustainability at local level. This is an area where it is very easy to find examples to support different viewpoints and a more structured analysis of past schemes and the reasons for their failures would be of help. In general, local interest and involvement has usually been sustained for short term interventions such as the 12 –18 months required for the type of elimination programme being analysed here. Of more concern is whether, given that few tsetse populations are truly isolated, effective barriers using these techniques could be maintained for years – and which techniques are suitable as long term barriers. A further argument might be that, if barriers are required it might make sense, both organisationally and in terms of building on local involvement and awareness created during the elimination phase, to use the same technology for the elimination work. This might therefore also be more cost-effective.

6.5 Achieving Other Goals: Saving Forex, Employing Local Labour, Alleviating Poverty

In Section 2, while reviewing past cost calculations, the practice of adjusting such costs to encourage the adoption of projects using little foreign exchange and creating local employment was mentioned. This use of 'shadow prices' is less frequently undertaken now than it was in the 1970s and 1980s, although, as mentioned, a similar procedure is currently used to assign higher weights to benefits accruing to poor people than to benefits which are mainly taken up by other income groups. Using a high shadow price for foreign exchange would mitigate against the use of SIT and SAT as compared to traps, targets and ITC. Using a low shadow price for local labour would have the same effect. Since the Lake Victoria basin has a high concentration of poor people (Figure 4), the selection of the project area ensures that a high proportion of benefits accrue to poor people, principally to those at risk of contracting sleeping sickness and to poor livestock keepers. However, the poverty alleviation goal would be met by each of the control strategies, although achieved more quickly by SAT than traps or ITC and least quickly by SIT plus suppression. Thus, while the need to save forex or increase local employment could influence choice of technique, the choice of project area and subsequent measures to influence how benefits are taken up are the main factors in working towards poverty alleviation. Nevertheless, given limited government resources and the need to reduce debt, cost-effectiveness must be a major component of any poverty alleviation strategy.

7. CONCLUSIONS

7.1 Key Results

The figures resulting from this analysis thus provide a number of useful and important insights for decision-makers choosing approaches to create tsetse-free zones. The results largely confirm previous knowledge and opinion as to which techniques are 'expensive' and which are 'cheaper'. The results given in Table 10 showed that the costs km^{-2} of the different techniques when used to eliminate isolated tsetse populations increased in the order: ITC (US$ 130-400), traps for savannah flies (US$ 400-500), SAT (US$ 500-600), traps for *G. fuscipes* (US$ 900) and SIT (US$ 1,000 – 1,300). It is worth noting that overall when compared to earlier studies:

- technical improvements and refinements have tended to reduce slightly the real cost of the different techniques; and
- the cost differentials among them have also narrowed somewhat.

For non-isolated tsetse populations, the addition of a barrier on one side of a square block to prevent reinvasion, covering 10% of the treated area, increased total costs km^{-2} by 15 – 20% if ITC were used and 30 – 60% if traps were used (Table 12). This calculation was based on needing to maintain the barrier for only three years. However, if a longer period were required these figures would increase. If invasion pressure came from two sides, so that two barriers were needed, the incremental costs would be approximately doubled.

These cost calculations go beyond the more commonly-cited figures in that:

- they include an estimate of non-field costs for administrative overheads, tsetse surveys and monitoring and accompanying studies (epidemiological, socio-economic and environmental); and
- they take into account the differences in timing inherent in the different techniques, ranging from three months to complete 5 cycles of aerial spraying if using SAT, to five years to allow for the build up of a tsetse colony followed by three months of suppression and some eighteen months of release of sterile males if using SIT as set out in ADB *et al.*, 2004.

For this reason, these calculations provide a truly comparable basis for choosing among techniques for eliminating tsetse populations on the basis of cost. The provisos are that these costs do not, however, include the costs of accompanying measures to deal with the disease in people and livestock, as these would be very much the same across the different techniques. Similarly, since the focus of this particular work was to inform decision-making in the context of the large scale programmes to create tsetse-free zones, alternative strategies for ongoing control of either the vector or of the disease using chemotherapy or chemoprophylaxis were not costed out here. A discussion of such cost comparisons can be found in Shaw (2003).

In the cost hierarchy, suppression plus SIT is necessarily the most expensive because SIT is additional to other techniques which in themselves have the potential to eliminate tsetse, and has longest lead time, which has a large impact on the costs once the time factor is taken into consideration. In any case, the use of SIT is recommended only in areas or pockets of areas where other techniques are not able to fully eliminate the tsetse population. Since some techniques are more suited to certain species of fly or to particular situations, it is likely that combinations of techniques will offer the best possibility of eliminating the tsetse in particular areas, especially where more than one tsetse species is present. However, even when combining techniques, considerations of cost are important, and the inclusion of SIT in the mixture of combinations will increase the cost far more than using lower cost approaches. If different techniques are to be combined, particular consideration needs to be given to the extent to which these techniques complement each other organisationally, as well as in their entomological effectiveness, as this has important implications for administrative overheads and the cost of accompanying studies.

When considered alongside the other criteria informing choice of technique it is very clear that the tsetse fly continues to pose a complex challenge, so that there is no 'one size fits all' solution to dealing with it. This is a challenge for PATTEC as its programme for the creation of tsetse-fly zones moves closer to realisation: the challenge is particularly great with respect to choice of technology. Each technique has its strengths and weaknesses which must be measured against relative cost and relative effectiveness so that each is applied in those situations which best warrant its deployment.

7.2 Identifying and Filling Knowledge Gaps

The discussion in Section 6 highlighted a number of specific areas where more work is needed to inform decision making.

- On the technical side, more knowledge is needed on the control of *G. fuscipes* using traps and the results of trials using ITC demonstrating its potential to eliminate populations are eagerly awaited.
- Furthermore, despite the extensive knowledge and widely ranging existing experience in controlling different tsetse species in different habitats, there are still situations where the technical parameters which should guide choice of technique need clarification or further investigation. Although the impact of the different techniques can be modelled, under ideal conditions and in response to defined departures from these ideal conditions, there is much debate about the speed with which the different techniques can operate and the situations in which they perform best. Economic analyses are necessarily dependent on the availability of accurate technical data and thus, while the orders of magnitude calculated in this analysis are likely to be correct, they are subject to considerable variation in some field situations. Decision-makers would benefit greatly from clear technical guidelines setting out the entomological and environmental situations, project objectives and scale on which each tsetse control technique performs best and the criteria which should determine the choice of one technique over another. It is strongly recommended that consideration be given to producing such guidelines, ideally in the form of a joint paper written by the leading entomologists involved in developing each technique and reflecting some consensus among these experts. This exercise falls within the remit of PAAT, which should build on information already generated by PAAT and others, and fill gaps where they exist. This will then provide an invaluable resource for PATTEC to consult in carrying out its mission effectively.
- Building on such guidelines, to further inform the debate on choice of technique it would also be useful to have a clearer idea of why past schemes have failed to meet their goals or failed to be sustained. There has been a tendency to argue 'anecdotally' that this technique doesn't work because look what happened in this case or that case. Reasons for failure tend to be combinations of (i) funding not sustained; (ii) organisation not sustained; (iii) reinvasion often due to lack of barriers or deployment on too small a scale; and only lastly (iv) poor intrinsic performance of chosen tsetse control technique. In the context of a long-term initiative like PATTEC, a small investment in a 'lessons learnt' exercise, cataloguing past schemes and their strengths and weaknesses could prove extremely valuable. Time and scale are important issues, so the length of time for

which initiatives worked effectively would need to be analysed as well as the scale on which they were deployed.

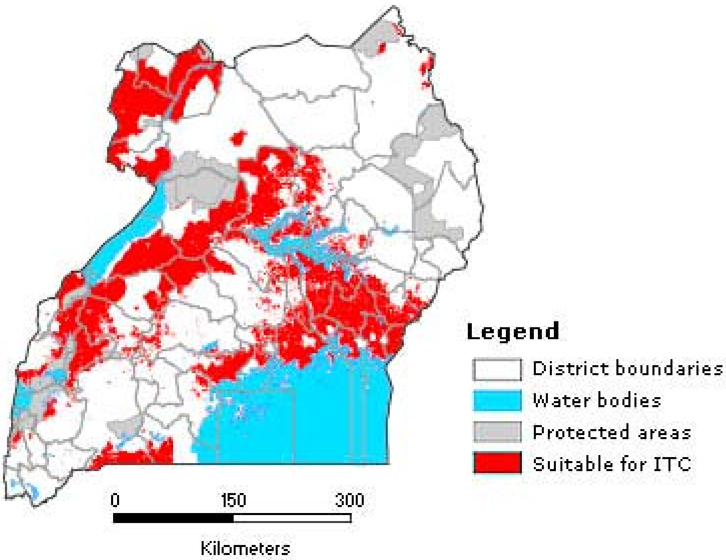
- Clearly final decisions on choice of technique must await updated tsetse distribution maps based on field surveys.
- On the organisational side, both from the economic and the planning point of view, a better idea of what level of administrative overheads and accompanying studies (environmental, socio-economic and epidemiological) is necessary and whether the requirement varies according to the technique being used. As the summary costings showed, these make a great difference to costs, adding as much as US$ 250 km^{-2} and thus in some cases exceeding operational costs. This is an area where guidelines are urgently needed as well as investigations as to the extent to which these costs vary according to the scale of project and the technique used.

7.3 Future Developments

This costing exercise has shown that it is possible to derive robust, order-of-magnitude costs for various tsetse control methods. A possible next step, as proposed by Shaw *et al*. (2006) would be to go on to mapping these. A first step would be to compile maps which indicate the suitability of each area for deployment of the different techniques. As an illustrative example, Figure 11 illustrates how this could be done for ITC. Given typical herd compositions, in order to find 4 large cattle km^{-2} to treat, the minimum cattle population km^{-2} would need to be 10. Figure 11 shows, in red, those areas which have more than 10 head of cattle km^{-2} and a 30% or greater probability of containing tsetse.

Following the mapping of which techniques are feasible, the next step would be to assign monetary values to the mapped techniques, then go on to produce financial maps, similar to the benefit maps produced by Shaw *et al*. (2006). These would map how much it would cost to deal with tsetse using the various feasible techniques in the areas where they could be applied. Such cost maps could then be considered alongside benefit maps and poverty maps and together would provide an enormously powerful decision tool for priority-setting and planning (for example choosing which technique to use where) in the field.

Figure 11: *Mapping technical feasibility: areas with 30% or greater probability of tsetse presence and 10 or more cattle km^{-2}.*



Such cost maps would provide a tool that could guide both policy and technical decisions, which would be of great value to tsetse and trypanosomiasis interventions in the context of Africa's bold new initiatives and commitment to dealing with this problem.

8. REFERENCES

ADB, IAEA and PATTEC (2004) *Integrated area-wide programme for trypanosomiasis-free zones in Uganda*. ADB, IAEA and PATTEC, Uganda.

ADF (2004) *Multinational project: creation of sustainable tsetse and trypanosomiasis free areas in East and West Africa. Appraisal Report.* Agricultural and rural development departments, ADB Agriculture and Rural Development Departments: Operations Central and West (OCAR) and Operations North East and South ONAR. Downloadable from: http://www.afdb.org/pls/portal/docs/PAGE/ADB_ADMIN_PG/DOCUMENTS/OPERATIONSINFORMATION/ADF_BD_WP_2004_152_E.PDF

Allsopp, R and Hursey, B (2004) Insecticidal control of tsetse. In: Maudlin, I, Holmes, P and Miles, M (eds.) *The Trypanosomiases*. CABI Publishing, Wallingford, UK, pp. 491-507.

Barrett, J (1997) *Economic Issues in Trypanosomiasis Control*. Natural Resources Institute, Chatham, UK.

Brandl, F E (1988) Cost of different methods to control riverine tsetse in West Africa. *Tropical Animal Health and Production*, 20:67-77.

Bourn, D, Reid, R, Rogers, D, Snow, B and Wint, W (2001) *Environmental Change and the Autonomous Control of Tsetse and Trypanosomosis in Sub-Saharan Africa.* Commissioned by the Animal Health Programme of DFID's Rural Livelihoods Department. Environmental Research Group Oxford (ERGO), Oxford, UK.

Bourn, D, Grant, I, Shaw, A and Torr, S (2005) Cheap and safe tsetse control for livestock production and mixed farming in Africa. *Aspects of Applied Biology,* 75:81-92.

Budd, L (1999) *DFID-funded Tsetse and Trypanosome Research and Development since 1980 - Volume 2, Economic Analysis.* DFID, London, U.K.

COCTU (2004) *National Policy on creation of tsetse and trypanosomiasis-free zones.* COCTU, Kampala, Uganda.

Davies, H (1964) The Eradication of Tsetse in the Chad River System of Northern Nigeria. *Journal of Applied Ecology,* 1:387-403.

Davies, H (1971) Further Eradication of Tsetse in the Chad and Gongola River Systems of North-Eastern Nigeria. *Journal of Applied Ecology,* 8:568-578.

Emwanu T, Okwi, PO, Hoogeween, J G and Kristjanson, P (2003) *Where are the poor? Mapping patterns of well-being in Uganda*. Uganda Bureau of Statistics (UBOS), Kampala, Uganda.

Feldmann, U (2004) The sterile insect technique a component of area-wide integrated pest management of tsetse. In: Maudlin, I, Holmes, P and Miles, M (eds.) *The Trypanosomiases*. CABI Publishing, Wallingford, UK, pp.565–582.

Fèvre, E M, Picozzi, K, Fyfe, J, J, Waiswa, C, Odiit, M, Coleman, P G and Welburn, S C (2005) A burgeoning epidemic of sleeping sickness in Uganda. *Lancet,* 366:745-747.

Geerts, S and Holmes, P (1998) *Drug management and parasite resistance in bovine trypanosomiasis in Africa.* PAAT Technical and Scientific Series No. 1. FAO, Rome, Italy.

Gilbert, M, Jenner, C, Pender, J, Rogers, D, Slingenbergh, J and Wint, W (2001) The Programme Against African Trypanosomiasis Information System (PAATIS) In: Black, S N and Seed, J R (eds) *World Class Parasites: Volume 1 – The African Trypanosomes*, 11–24. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Gittinger, J P (1982) *Economic Analysis of Agricultural Projects*. EDI series in economic development. Johns Hopkins Press, Baltimore, USA.

Grant, I (2001) Insecticides for tsetse and trypanosomiasis control: is the environmental risk acceptable? *Trends in Parasitology,* 17:1.

Hargrove, J W (2003a) *Tsetse eradication, necessity, sufficiency and desirability.* DFID Animal Health Programme, Edinburgh, UK.

Hargrove, J W (2003b) Optimized simulation of the control of tsetse flies *Glossina pallidipes* and *G.m. morsitans (Diptera: Glossinidae*) in Zimbabwe. *Bulletin of Entomological Research,* 93:19–29.

Hargrove, J W, Torr, S J, and Kindness, H M (2003) Insecticide-treated cattle against tsetse (*Diptera: Glossinidae*): what governs success? *Bulletin of Entomological Research* 93:203–217.

Hide, G, Tait, A., Maudlin I and Welburn, S C (1996) The origins, dynamics and generation of *Trypanosoma brucei rhodesiense* epidemics in East Africa. *Parasitology Today,* 12: 50-55

Holden, S (1999) The economics of the delivery of veterinary services. *Revue Scientifique et Technique de l'Office international des Epizooties,* 18:425-439.

Holmes, P H, Eisler, M C and Geerts, S (2004) Current Chemotherapy of Animal Trypanosomiasis. In: Maudlin, I. Holmes, P and Miles, M (eds.) *The Trypanosomiases*. CABI Publishing, Wallingford, UK, pp.431-444.

Kamuanga, M, Swallow, B M, Sigué, H, Bauer, B (2001) Evaluating contingent and actual contributions to a local public good: tsetse control in the Yalé Agro-pastoral Zone, Burkina Faso. *Ecological Economics,* 39:115-130.

Kgori, P M, Modo, S and Torr, S J (2006). The use of aerial spraying to eliminate tsetse from the Okavango Delta of Botswana. *Acta Tropica* 99:184-199

Lancien, J (1991) Lutte contre la maladie du sommeil dans le sud-ouest Ouganda par piégage des glossines. *Annales de la Société belge de Médecine tropicale,* 71(Suppl. 1):35-47.

Lancien, J and Obayi, H (1993) La lutte contre les vecteurs de la Maladie du Sommeil. *Bulletin de la Société Française de Parasitologie*, 11:107–117.

Leonard, D K (ed.) (2000) *Africa's changing markets for health and veterinary services.* Macmillan Press, Basingstoke, UK.

Magona, J W, Walubengo, J, Odiit, M, Okedi, L A, Abila, P, Katabazi, B K, Gidudu, A M, Olaho-Mukani,W, (2005) Implications of the re-invasion of Southeast Uganda by *Glossina pallidipes* on the epidemiology of bovine trypanosomiasis. *Veterinary Parasitology,* 128:1–9.

Mattioli, R C, Feldmann, U, Hendrickx, G, Wint, W, Jannin, J and Slingenbergh, J. (2004) Tsetse and trypanosomiasis intervention policies supporting sustainable animal-agricultural development. *Journal of Food, Agriculture and Environment*, 2:310–314.

Maudlin, I, Holmes, P and Miles, M (eds.) *The Trypanosomiases*. CABI Publishing, Wallingford, UK.

McDermott, J J and Coleman P G (2001) Comparing apples and oranges – model-based assessment of different tsetse-transmitted control strategies. *International Journal for Parasitology,* 31: 603-609.

Mullins, G, Allsopp, R, Nkori, P, Kolyane, M and Phillemon-Motsu, T K (1999) The effects of tsetse fly control on tourism in the Okavango Delta of Botswana. *ISCTRC Publication no. 119, 24th Meeting, 1997, Maputo, Mozambique.* ISCTRC, Nairobi, Kenya, pp. 555-562

Onyango, R J, van Hoeve, K, de Raadt, P (1966) The epidemiology of *Trypanosoma rhodesiense* sleeping sickness in Alego location, central Nyanza, Kenya I. Evidence that cattle may act as reservoir hosts for trypanosomes infective to man. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 60:175-82.

Pender, J, Jenner, C, Wint, W and Gilbert, M (2001) *Programme against Animal Trypanosomiasis Information System (PAAT–IS).* Software, website and data CD produced by Environmental Research Group Oxford Ltd on behalf of the Natural Resources Institute, Chatham, for FAO, Rome, Italy and DFID, London, UK. http://www.fao.org/paat/html/home.htm

Picozzi, K, Tilley, A, Fèvre, E M, Coleman, P G, Magona, J W, Odiit, M, Eisler, M C, & Welburn, SC (2002). The diagnosis of trypanosome infections: applications of novel technology for reducing disease risk. *African Journal of Biotechnology,* 1:39-45

Picozzi, K, Fèvre, E M, Odiit, M, Carrington, M, Eisler, M, Maudlin, I and Welburn S (2005) Sleeping sickness in Uganda: a thin line between two fatal diseases. *British Medical Journal,* 331:1238–1241.

Putt, S N H, Shaw, A P M, Matthewman, R W, Bourn D M, Underwood, M, James, A D, Hallam, M J and Ellis, P R. (1980) *The Social and Economic Implications of Trypanosomiasis Control - a study of its impact on livestock production and rural development in northern Nigeria.* Veterinary Epidemiology and Economics Research Unit (VEERU), Study no. 25, Reading University

Robinson, T P (2002) *Decision support for trypanosomiasis control in Uganda*. Report to The Right Honourable Mary Myugenyi, Minister of State for Animal Industry, Government of Uganda. People Livestock and Environment Working Paper No. 3. Nairobi: International Livestock Research Institute (ILRI), January, 2002.

Robinson, T, Rogers, D J and Williams, B (1997) Mapping tsetse habitat suitability in the common fly belt of southern Africa using multivariate analysis of climate and remotely sensed vegetation data. *Medical and Veterinary Entomology,* 11:235–245.

Rogers, D J (1988). A general model for the African trypanosomiases. *Parasitology*, 97:193–212.

Rogers, D J and Robinson, T P (2004) Tsetse Distribution. In: Maudlin, I, Holmes, P and Miles, M (eds.) *The Trypanosomiases*. CABI Publishing, Wallingford, UK, pp. 139-179.

Rogers, D J, Emwanu, T and Robinson, T. (2006) *Poverty Mapping in Uganda: An Analysis Using Remotely Sensed and Other Environmental Data*. PPLPI Working Paper No. 36. Rome: FAO's Pro-Poor Livestock Policy Initiative (PPLPI). http://www.fao.org/ag/againfo/projects/en/pplpi/docarc/wp36.pdf

Shaw, A P M (2003) *Economic Guidelines for Strategic Planning of Tsetse and Trypanosomiasis Control in West Africa*. PAAT Technical and Scientific Series No. 5. FAO, Rome, Italy.

Shaw, A (2004) The Economics of African Trypanosomiasis. In: Maudlin, I, Holmes, P and Miles, M (eds.) *The Trypanosomiases*, CABI Publishing, Wallingford, UK, pp. 369–402.

Shaw, A P M, Zessin, K H and Münstermann, S (1994) Modelling the economics of tsetse control using mono-pyramidal traps in Côte d'Ivoire. In: Rowland, G. J., Kyule, M. and Perry, B. D. (eds.) Proceedings of the 7th International Symposium on Veterinary Epidemiology and Economics, Nairobi, Kenya. *The Kenya Veterinarian,* 18:244–246

Shaw, A, Hendrickx, G, Gilbert, M, Mattioli, R, Codjia, V, Dao, B, Diall, O, Mahama, C, Sidibé, I and Wint, W (2006) Mapping the benefits: a new decision tool for tsetse and trypanosomiasis interventions. DFID Animal Health Programme (AHP) and FAO Programme Against African Trypanosomiasis, Edinburgh, UK.

Swallow, B M (2000) *Impacts of Trypanosomiasis on African Agriculture*. PAAT Technical and Scientific Series No. 2, FAO, Rome, Italy.

Swallow, B M and Woudyalew, M (1994) Evaluating willingness to contribute to a local public good: application of contingent valuation to tsetse control in Ethiopia. *Ecological Economics*, 11:153-161.

Thornton, P K, Kruska, R K, Henninger, N, Kristjanson, P M, Reid, R S, Atieno, F, Odero A and Ndegwa, T (2002) *Mapping poverty and livestock in developing countries.* ILRI, Nairobi, Kenya.

Thuranira, C (2005) *Socio-economic factors influencing livestock-keeping dynamics in smallholder crop-livestock systems in Western Kenya*. PhD thesis, University of Edinburgh, Edinburgh, UK.

Thrusfield, M (1995) *Veterinary Epidemiology* – 2nd Edition. Blackwell Science, Oxford, UK.

Torr, S J, Hargrove, J W and Vale, G A (2005) Towards a rational policy for dealing with tsetse. *Trends in Parasitology,* 11:537-541.

UBOS (2002) *Uganda population and housing census: provisional results.* Uganda Bureau of Statistics (UBOS), Entebbe, Uganda.

UBOS (2004) *Report on the Agriculture Module, piggy-backed onto the Population and Housing Census.* UBOS), Entebbe, Uganda.

Vale, G and Torr, S (2004) Development of bait technology to control tsetse. In: Maudlin, I, Holmes, P and Miles, M (eds.) *The Trypanosomiases*, CABI Publishing, Wallingford, UK, pp. 509–523.

Vale, G and Torr, S (2005) User-friendly models of the costs and efficacy of tsetse control: application to sterilisation and insecticidal techniques. *Medical and Veterinary Entomology,* 19:293-305.

Vale, G A, Grant, I F, Dewhurst, C F, Aigreau, D (2004) Biological and chemical assays of pyrethroids in cattle dung. *Bulletin of Entomological Research,* 94:273-282.

Waiswa C, Picozzi, K, Katunguka-Rwakishaya, E, Olaho-Mukani, W, Musoke, RA, Welburn, SC (2006) *Glossina fuscipes fuscipes* in the trypanosomiasis endemic areas of south eastern Uganda: Apparent density, trypanosome infection rates and host feeding preferences *Acta Tropica,* 99:23-29

Welburn, S C, Coleman, P G, Maudlin, I, Fèvre, E M, Odiit, M and Eisler, M C (2006) Crisis, what crisis? Control of Rhodesian sleeping sickness. *Trends in Parasitology*, 22:123–128.

Wilson, S G (1953) The Control of *Glossina pallidipes fuscipes* Newstead in Kenya Colony. *Bulletin of Entomological Research*, 44:711-728.

Wint, W (2002) *Kilometre resolution tsetse fly distribution maps for the Lake Victoria Basin and West Africa*. Report to FAO/IAEA Joint division by the Environmental Research Group Oxford (ERGO), Oxford, UK.

Woudyalew, M, Swallow, B, Rowlands, G J. Leak, S G A, d'Ieteren, G D M and Nagda, S M (1999) Economic Benefits to Farmers of six years of application of an insecticidal 'Pour-on' to Control Tsetse in Ghibe, Southwest Ethiopia. *ISCTRC Publication no. 119, 24th Meeting, 1997, Maputo, Mozambique.* ISCTRC, Nairobi, Kenya, pp. 578–586.

WHO (1998) *African Trypanosomiasis: Control and Surveillance. Report of a WHO Expert Committee.* WHO Technical Report Series No. 881, WHO, Geneva, Switzerland.

WHO (2006) *Fact sheet no. 259 on trypanosomiasis (updated).* Obtainable from: http://www.who.int/mediacentre/factsheets/fs259/en/

9. ANNEX TABLES

Table A1: *Discount factors used.*

Year	10% Discount factor	5% Discount factor
1	1.464	1.216
2	1.331	1.158
3	1.210	1.103
4	1.100	1.050
5	1.000	1.000
6	0.909	0.952
7	0.826	0.907
8	0.751	0.864
9	0.683	0.823
10	0.621	0.784

Note: All figures are discounted to their 'present value' in Year 5, which is the year when tsetse control in the field starts for all strategies. Years 1 – 4 are used for preparatory activities, some of which, such as tsetse surveys, are common to all strategies. Others, such as build up of tsetse breeding colonies or repair of airstrips, are specific to one or more strategies. The present value is calculated by multiplying the cost incurred in each year by the discount factor for that year and then adding up the resulting discounted figures (see Gittinger, 1982 for a detailed explanation of the method and Shaw, 2003 for a discussion of it in the context of tsetse control.)

Table A2: *Details of basic costing for traps.*

Capital items	Number required	Unit cost US$	Total cost US$	% Share for project	Years usable	Annual cost US$
Specialised equipment						
Traps	40,000	8	320,000	100	1	320,000
GPS Sets	30	30	900	100	3	300
Training course for field staff	30	180	5,400	100	3	1,800
Total cost of specialised equipment			**326,300**			**320,300**
General equipment						
4x4 Vehicle + extras for field work	1	35,000	35,000	100	3	11,667
Lorry	1	50,000	50,000	100	3	16,667
Laptop computer	0	3,000	0	100	3	0
Camping equipment/team	25	400	10,000	100	2	5,000
Cost per team			**95,000**			**33,333**
Number of teams	15					
Total cost general equipment			**1,425,000**			**500,000**

Table A2 *continued on next page*

Recurrent costs	Number required	Unit cost US$	Total cost US$	% Share for project	Years usable	Annual cost US$
Specialised equipment running						
Deltamethrin	400	150	60,000	100	1	60,000
Herbicide	40,000	1.2	48,000	100	1	48,000
Odours - Octenol sachets	40,000	1.0	40,000	100	1	40,000
Acetone	800	300	240,000	100	1	240,000
Total cost of running specialised equipment			**388,000**			**388,000**
Vehicle running costs						
4x4 - fuel	1	4,000	4,000			
4x4 - spares and maintenance	1	3,000	3,000			
Lorry - fuel	1	4,000	4,000			
Lorry - spare parts and maint.	1	3,000	3,000			
Vehicle running costs per team			**14,000**			
Number of teams required	15					
Total vehicle running			**210,000**			**210,000**
Staff salaries						
Team leader	1	5000	5,000			
Entomological assistant	3	3100	9,300			
Drivers	2	3100	6,200			
Casual workers (village or other)	20	750	15,000			
Salaries for one team			**35,500**			
Number of teams required	15					
Total salaries			**532,500**			**532,500**
Staff allowances						
Allowances for senior staff in team	1	5000	5,000			
Junior staff allowances	5	3400	17,000			
Allowances for one team			**22,000**			
Number of teams required	15					
Total allowances			**330,000**			**330,000**
Other running costs						
Stationery	15	240	3,600			
Batteries for GPS Units	30	30	900			
Misc, *e.g.* first aid, other	15	300	4,500			
Total other running costs			**9,000**			**9,000**
Totals			**3,220,800**			**2,289,800**
Total km^{-2} per year						**228.98**

Table A2 *(addendum): Sensitivity analysis for traps: using fewer vehicles and reducing labour costs*

Total cost in US$			**2,718,300**			**2,020,633**
US$ km^{-2} per year						**202.06**

Note: Here the supervisor's vehicle is shared between 3 teams and the labour costs for the teams are halved, in line with local rather than project salaries, or assuming a low cost community labour input.

Table A3: *Details of basic costing for aerial spraying using the sequential aerosol technique.*

Capital items	Number required	Unit cost US$	Total cost US$	% Share for project	Years usable	Annual cost US$
Specialised equipment						
Rehabilitation of airport	1	100,000	100,000	25	4	6,250
Training course for field staff	10	180	1,800	100	3	600
Total cost of specialised equipment			**101,800**			**6,850**
General equipment						
4x4 Vehicle + extras for field work	5	35,000	175,000	30	3	17,500
Radio sets for 5 marker teams	5	3,000	15,000	100	3	5,000
Camp construction and equipment	1	20,000	20,000	25	2	2,500
Total cost general equipment			**210,000**			**25,000**

Recurrent costs	Number required	Unit cost US$	Total cost US$	% Share for project	Years usable	Annual cost US$
Specialised equipment running						
Airport maintenance	1	50,000	50,000	25	6	2,083
Insecticide + Flying time	10,000	350	3,500,000	100	1	3,500,000
Droplet monitoring (estimate)	10,000	15.0	150,000	100	1	150,000
Fixed charges for flying	Incl. above					
Total cost of running specialised equipment			**3,700,000**			**3,652,083**
Vehicle running costs						
5 ground marker teams						
4x4 - fuel	1	4,000	4,000			
4x4 - spares and maintenance	1	3,000	3,000			
Vehicle running costs per team			7,000			
Number of teams required	5					
Total vehicle running			**35,000**			**35,000**
Staff salaries						
Team leader	1	6,000	6,000			
Entomological assistant	1	3100	3,100			
Drivers	1	3100	3,100			
Casual workers (village or other)	0	750	0			
Salaries for one team			12,200			
Number of teams required	5					
Total salaries			**61,000**			**61,000**
Staff allowances						
Allowances for senior staff in team	1	1875	1,875			
Junior staff allowances	2	1275	2,550			
Allowances for one team			4,425			
Number of teams required	5					
Total allowances			**22,125**			**22,125**

Table A3 *continued on next page*

Other running costs				
Stationery	5	100	500	
Batteries for GPS Units	0	30	0	
Misc, *e.g.* first aid, other	5	150	750	
Total other running costs			**1,250**	**1,250**
Totals			**4,131,175**	**3,803,308**
Total km^{-2}			**413.12**	**380.33**

Notes: Flying 5 cycles for elimination. Ground marker teams costed above. Spraying takes 39 days, range taken to be 35-50 days to which is added 5 weeks preparation and set up time, so maximum some 12 weeks are spent in the field in total calculated as 30% of a year. The flying and insecticide estimates are based on the Botswana experience, where the cost km^{-2} ranged from US$ 270 – 290 (Allsopp and Hursey, 2004 and personal communication R Allsopp). Costs have been increased slightly here to reflect inflation and the higher flying time costs (US$ 700) incorporated in ADB *et al*. 2004. The aerial spraying component of these costings needs more detailed analysis and quantification. The repairs to the airport are assumed to be done in the same year as the spraying, however, an alternative scenario would have them done a year earlier, with the result that these would need to be discounted, but the effect on the cost km^{-2} would be negligible.

Table A4: *Details of basic costing for sterile insect technique.*

Capital items	Number required	Unit Cost US$	Total cost US$	% Share for project	Years usable
Specialised equipment					
Mass rearing 6 insectary modules	6	833,333	5,000,000	25	10
Recruitment of flies from Buvuma	1	30,000	30,000	25	10
Equipment lasting 10 years	1	2,246,400	2,246,400	25	10
Equipment lasting 5 years	1	217,000	217,000	25	5
Rehabilitation of airport	1	100,000	100,000	25	5
(a) Total cost of specialised equipment			**7,593,400**		
General equipment					
4x4 Vehicle for blood meal	1	25,000	25,000	25	5
Office furniture+internet	1	30,000	30,000	25	10
Pick-up truck	2	40,000	80,000	25	5
Scanners and computers	1	32,000	32,000	25	3
(b) Total cost general equipment			**167,000**		
Specialised equipment running					
Air strip maintenance	1	50,000	50,000	100	6
Blood meal requirements	365	1,000	365,000	100	1
(c) Total specialised running			**415,000**		
Dispersal of sterile males					
Flying time	3510	700	2,457,000	100	1
Chilled release system	1	10,000	10,000	100	1
(d) Total cost of fly release			**2,467,000**		
Vehicle running costs and utilities					
4x4 - fuel	1	2,400	2,400	100	1
4x4 - spares and maintenance	1	1,500	1,500	100	1
Other fuel costs annually	1	20,000	20,000	100	1

Electricity and water	1	184,000	184,000	100	1
(e) Total vehicle running			**207,900**		
Staff salaries					
Supervision of mass rearing	1	21,600	21,600		
Staff salaries per module	6	27,600	165,600		
Consultants	1	2,500	2,500		
Meetings	1	3,100	3,100		
(f) Total salaries			**192,800**		
Staff allowances					
Allowances for driver	1	2800	2,800	100	1
(g) Total allowances			**2,800**		
Other running costs					
Stationery	30	240	7,200		1
Batteries for GPS Units	30	30	900		1
Misc, *e.g.* first aid, other	30	300	9,000		1
(h) Total other running costs			**17,100**		

Note: Items lasting ten years are not replaced during the period analysed. Items lasting 5 years are replaced in year 5 and items lasting 3 years are replaced in years 4 and 7.

The figures in the main text Table 8 are derived as follows:

- Capital items year 1 = a + b
- Capital items year 4 = scanners and computers (just above total b)
- Capital items year 6 = half the costs of equipment lasting 5 years and airport rehabilitation (just above total a) + vehicles (general equipment, above total b)
- Recurrent costs = c + e + f + g + h
- Fly release costs = d

Table A5: *Cost of accompanying studies, surveys and administration for Traps, ITC and SAT in US$.*

Year	Office support and admin.	Entomo-logical survey	Entomo-ogical monitoring	Socio-economic study	Environ-mental Monitoring	Sleeping sickness surveys	Parasito-logical baseline data	Training and expert services	Total costs
1		0	14,975		0	0	0		14,975
2		0	14,975		0	0	0		14,975
3	57,425	153,250	14,975		0	19,893	0	25	245,568
4	46,275	220,550	113,200	66,245	65,375	32,163	187,550	75	731,433
5	52,800	0	193,850	57,490	0	29,400	0	25	333,565
6	89,000	0	192,350	57,490	0	29,400	0	0	368,240
7	26,000	0	191,850		0	29,400	0	0	247,250
8	26,000	0	95,925		0	0	0	0	121,925
9		0	48,213		0	0	0	0	48,213
Total	**297,500**	**363,050**	**880,313**	**181,225**	**65,375**	**140,255**	**187,550**	**125**	**2,126,143**
0% discount rate:									
US$ km^{-2} tsetse-free	29.8	37.4	88.0	18.1	6.5	14.0	18.8	0.0	212.6
% of non-field costs	14.0	17.6	41.4	8.5	3.1	6.6	8.8	0.0	100.0
5% discount rate:									
US$ km^{-2} tsetse-free	29.6	40.1	84.4	18.2	6.9	14.0	19.7	0.0	212.8
% of non-field costs	13.9	18.8	39.7	8.5	3.2	6.6	9.3	0.0	100.0
10% discount rate:									
US$ km^{-2} tsetse-free	29.5	42.8	81.7	18.3	7.2	14.0	20.6	0.0	214.1
% of non-field costs	13.8	20.0	38.2	8.5	3.4	6.5	9.6	0.0	100.0

Source: Adapted from ADB *et al.*, 2004.

Table A6: *Cost of accompanying studies, surveys and administration for SIT (per block of 10,000 km²) in US$.*

Year	Office support and admin.	Entomo-logical survey	Entomo-ogical monitoring	Socio-economic study	Environ-mental Monitoring	Sleeping sickness surveys	Parasito-logical baseline data	Training and expert services	Total costs
1	57,425	0	14,975		0	0	0	25	72,425
2	46,275	0	14,975		0	0	0	75	61,325
3	40,525	153,250	14,975		0	19,893	0	75	228,718
4	44,500	220,550	113,200	66,245	65,375	32,163	187,550	50	729,633
5	52,800	0	193,850	57,490	0	29,400	0	25	333,565
6	89,000	0	192,350	57,490	0	29,400	0	0	368,240
7	78,000	0	191,850		0	29,400	0	0	299,250
8	35,380	0	95,925		0	0	0	0	131,305
9	0	0	96,425		0	0	0	0	96,425
10	0	0	96,175		0	0	0	0	96,175
Total	**443,905**	**363,050**	**1,024,700**	**181,225**	**65,375**	**140,255**	**187,550**	**250**	**2,417,060**
0% discount rate:									
US$ km^{-2} tsetse-free	44.4	37.4	102.5	18.1	6.5	14.0	18.8	0.0	241.7
% of non-field costs	18.4	15.5	42.4	7.5	2.7	5.8	7.8	0.0	100.0
5% discount rate:									
US$ km^{-2} tsetse-free	45.4	40.1	96.0	18.2	6.9	14.0	19.7	0.0	240.1
% of non-field costs	18.9	16.7	40.0	7.6	2.9	5.8	8.2	0.0	100.0
10% discount rate:									
US$ km^{-2} tsetse-free	46.8	42.8	90.9	18.3	7.2	14.0	20.6	0.0	240.7
% of non-field costs	19.5	17.8	37.8	7.6	3.0	5.8	8.6	0.0	100.0

Source: Adapted from ADB *et al*., 2004.