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Estimating the costs of tsetse control options: An example for Uganda☆

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ABSTRACT

Decision-making and financial planning for tsetse control is complex, with a particularly wide range of choices to be made on location, timing, strategy and methods. This paper presents full cost estimates for eliminating or continuously controlling tsetse in a hypothetical area of 10,000 km^2 located in south-eastern Uganda. Four tsetse control techniques were analysed: (i) artificial baits (insecticide-treated traps/targets), (ii) insecticide-treated cattle (ITC), (iii) aerial spraying using the sequential aerosol technique (SAT) and (iv) the addition of the sterile insect technique (SIT) to the insecticide-based methods (i–iii).

For the creation of fly-free zones and using a 10% discount rate, the field costs per km^2 came to US$283 for traps (4 traps per km^2), US$30 for ITC (5 treated cattle per km^2 using restricted application), US$380 for SAT and US$758 for adding SIT. The inclusion of entomological and other preliminary studies plus administrative overheads adds substantially to the overall cost, so that the total costs become US$482 for traps, US$220 for ITC, US$552 for SAT and US$993 – 1365 if SIT is added following suppression using another method. These basic costs would apply to trouble-free operations dealing with isolated tsetse populations. Estimates were also made for non-isolated populations, allowing for a barrier covering 10% of the intervention area, maintained for 3 years. Where traps were used as a barrier, the total cost of elimination increased by between 29% and 57% and for ITC barriers the increase was between 12% and 30%.

In the case of continuous tsetse control operations, costs were estimated over a 20-year period and discounted at 10%. Total costs per km^2 came to US$368 for ITC, US$2114 for traps, all deployed continuously, and US$2442 for SAT applied at 3-year intervals. The lower costs compared favourably with the regular treatment of cattle with prophylactic trypanocides (US$3862 per km^2 assuming four doses per annum at 45 cattle per km^2).

Throughout the study, sensitivity analyses were conducted to explore the impact on cost estimates of different densities of ITC and traps, costs of baseline studies and discount rates.

The present analysis highlights the cost differentials between the different intervention techniques, whilst attesting to the significant progress made over the years in reducing field costs. Results indicate that continuous control activities can be cost-effective in reducing tsetse populations, especially where the creation of fly-free zones is challenging and reinvasion pressure high.

☆ The views expressed in this publication are those of the author(s) and do not necessarily reflect the views or policies of FAO.

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1. Introduction

For the planner, the field of tsetse and trypanosomosis control poses a particularly complex decision-making problem. First, there is a wide range of intervention techniques to be assessed, which include either tackling the parasite by treating livestock with trypanocides, or controlling the vector through insecticide-treated traps or cattle, aerial spraying, ground spraying, the sterile insect technique (SIT) or combinations of these. Second, planners are faced with important choices relating to the location, scale and strategic objectives of interventions. All choices need to be aimed at optimising the use of resources, and therefore they must be grounded in a solid understanding of the economics of control operations.

Decision-support for spatial targeting of interventions is increasingly being provided by detailed maps on the distribution of human African trypanosomosis (HAT) (Cecchi et al., 2009; Simarro et al., 2010) and its risk (Simarro et al., 2012), as well as by maps of the economic losses caused by African animal trypanosomosis (Shaw et al., 2006; Wint et al., 2011). Modelling tsetse population dynamics has added a further tool for planning and decision-support (Hargrove, 2000, 2004; Vale and Torr, 2005; Kgori et al., 2006).

Records of the costs of different tsetse control activities have been kept since these types of operations began (e.g. Wilson, 1953; Davies, 1971). Most of the analyses were confined to one country and one control operation (Shaw, 2004), and only a few compared the costs of different techniques (Putt et al., 1980; Brandl, 1988; Barrett, 1997; Budd, 1999). Scientific publications normally focused on analysing the core components of field costs such as targets, traps, insecticide, flying time and producing sterile males in relation to the impacts of different techniques on tsetse populations. This reflects the fact that cost-effectiveness of evolving techniques is, by its nature, studied in the field as part of entomological experiments to test the efficacy of different approaches (e.g. Esterhuizen et al., 2011). Other types of cost have received less attention in the literature and there is a tendency to assume that non-core and non-field costs are broadly the same for all technologies. However, this is not necessarily the case, because of both intrinsic differences in how the various techniques work, and extrinsic factors, reflecting project structure, donor exigencies and country- and location-specific organisational attributes (Putt et al., 1980). With the exception of Brandl (1988), who also considered continuous tsetse control, the studies above all dealt exclusively with tsetse elimination schemes. However, a study, adopting the cost calculation methodology of Shaw et al. (2007), undertook a detailed estimate of the modelled cost of continuous control using targets in Kenya (McCord et al., 2012).

The objective of the present study was to produce a set of costings that covered the range of techniques currently being used either to control or to eliminate tsetse, in order to provide an economic insight into decisions on scale and strategic objectives. The methodology used is full costing, which includes field costs, administrative and other overheads, and the costs of initial studies. In order to anchor the work in a real location based on real plans and projects, the analyses have been based on a single country. It takes as its starting point the area initially targeted by the Pan-African Tsetse and Trypanosomosis Eradication Campaign (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 south of Lake Kyoga. Using available tsetse and cattle distribution maps (Wint, 2001; Wint and Robinson, 2007) and census data for Uganda, it was estimated that the core infested area of just under 21,000 km^2 contains approximately 910,000 cattle and 4.9 million rural inhabitants, more than half of whom (2.6 million) subsist on less than US$1 a day.

This work forms part of a broader exercise aimed at quantifying and mapping both benefits and costs of interventions against tsetse and trypanosomosis in a range of livestock production systems of eastern Africa (Cecchi et al., 2010; Wint et al., 2011).

2. Materials and methods

2.1. Tsetse species and study area

The most important species of tsetse fly present in the study area is *Glossina fuscipes fuscipes*, though recent surveys indicated that *Glossina pallidipes* is also present near the Kenyan border (Magona et al., 2005). In the cost analysis for the tsetse elimination scenario, all calculations were based on a theoretical, square-shaped intervention area of 10,000 km^2, homogenously infested by a single fly species. Operationally, this is a viable size for the creation of a tsetse-free zone using any one of the intervention techniques. The calculations and modelling were undertaken assuming that only one species of tsetse is present and hence different types of artificial bait or different species of sterile males are not required.

2.2. Tsetse control techniques

Four tsetse control techniques were included in the analysis: stationary baits (insecticide-treated traps or targets, sometimes baited with attractants), mobile baits (insecticide-treated livestock), aerial spraying and SIT. The initial focus of the analysis was on calculating the cost of eliminating tsetse to create tsetse-free zones, in line with the prevailing PATTEC strategy. Elimination is defined as the complete removal of tsetse from a defined area (Hargrove, 2005). An estimate of costs of continuous control operations using baits, aerial spraying or regular treatment using trypanocides was also made. It was assumed that 'control' suppressed but did not eliminate tsetse and hence required repeated application.

2.2.1. Artificial baits

Insecticide-treated traps rather than targets were selected for costing as stationary baits because these are more widely used in operations to control *G. fuscipes* in Uganda (Okoth et al., 1991; Lancien, 1991) and elsewhere (Green, 1994). Traps deployed at a density of 10 per km^2 achieved local reductions of about 99% in tsetse populations (Lancien, 1991; Lancien and Obayi, 1993). Used with odour baits against *morsitans* group flies at a density of 4 per km^2, they are able to eliminate these fly populations. In some locations infested by flies of the *palpalis* group, much higher trap densities have been used (Vale and Torr, 2004), so costs were estimated for 4, 10 and 20 traps per km^2. The costing approach used would apply equally well to targets, since these require the same infrastructure for setting up and servicing.

2.2.2. Mobile baits

The use of insecticide-treated cattle (ITC) as mobile baits offers the possibility of simultaneously controlling ticks, other vectors and/or nuisance insects and tsetse, and can thus be integrated into farmers' existing tick control regimes (Vale and Torr, 2004; Van den Bossche and De Deken, 2004). 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 et al., 1995). ITC's cost-effectiveness has been greatly enhanced by the demonstration that tsetse can effectively be controlled by only spraying the legs and bellies of cattle (Torr et al., 2007). Since 2006, ITC using restricted application has been deployed as part of a programme to halt the spread of *rhodesiense* sleeping sickness in south-eastern Uganda, where its main reservoir is in cattle (Welburn et al., 2006; Kabasa, 2007).

Measures for the protection of individual cattle compounds, such as insecticide-impregnated nets or fences, were not considered here. Although these can have an impact on overall tsetse populations (Bauer et al., 2006, Maia et al., 2010) they have not been used yet in this context or on a significant scale in Uganda.

2.2.3. Aerial spraying

Aerial application of insecticides to control tsetse is based on 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 from their pupae but before they deposit larvae. Usually five cycles are required, at roughly15-day intervals. This technique was successfully deployed in Botswana's Okavango delta to control *Glossina morsitans centralis* (Allsopp and Hursey, 2004; Kgori et al., 2006). It has also been extensively used in areas of Zimbabwe and, in 2010, in Ghana to control *Glossina tachinoides* and *Glossina palpalis gambiensis*. 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).

2.2.4. Sterile insect technique

Lastly, following the success in eliminating *Glossina austeni* from Unguja Island, Zanzibar (Vreysen et al., 2000), much interest has been shown in using SIT as a means of eliminating residual fly populations once the tsetse population of an area has been suppressed using an insecticidal method. SIT may thus contribute to area-wide integrated pest management programmes, which target an entire tsetse population (Feldmann, 2004). Whereas the other techniques can be used either for continuous control or suppression of fly populations, or to eliminate them, SIT is suitable only to eliminate small residual populations. Its use is primarily advocated for tackling situations where other techniques appear unable to remove the fly population completely (Feldmann and Parker, 2010).

For the estimates of the costs of continuous tsetse control rather than elimination, three of the techniques were costed: traps or ITC maintained permanently and SAT repeated at 3-year intervals. The use of SIT is not presently recommended for continuous control activities (Feldmann and Parker, 2010).

The costs provide a means for comparison and should not be interpreted as a recommendation for the exclusive deployment of any particular technique. In many situations, a combination of vector control methods may be most appropriate. In any case, chemotherapy for humans and cattle and some trypanocide prophylaxis for cattle would also be taking place.

For situations where elimination was the objective and tsetse populations were not isolated, the use of either trap or ITC barriers was considered (Hargrove, 2004; Vale and Torr, 2004; Van den Bossche and De Deken, 2004).

2.3. The use of trypanocides

Trypanocides are in use throughout the study area, most often for curative purposes, although some trypanocide prophylaxis takes place, as found in other parts of tsetse-infested Africa (Holmes et al., 2004). It is estimated that in dairy herds, on average, 1.9 doses per head per annum are given (Laker, 1998). In other cattle populations this is likely to be between 1 and 2 doses. Though the focus of this paper is tsetse control or elimination, the cost of trypanocide prophylaxis is also estimated to allow a comparison with the costs of continuous disease control.

2.4. Simulation model of tsetse population dynamics

The main focus of the analysis was on the costs of creating permanent tsetse fly free zones as outlined in African Development Bank (AfDB) et al. (2004). In order to model the time taken and the relative efficacy of each intervention technique, a simulation model of tsetse population dynamics was used (Vale and Torr, 2005). The values used for the model's main input parameters were:

- starting population: 5000 wild female and 2500 wild male tsetse per km^2, where 'wild' distinguishes the existing population from introduced, reared flies, in particular sterile males;
- baseline age- and sex-specific death rates for uncontrolled tsetse populations: these were set out in Vale and Torr (2005) and then 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: these were taken from the literature as explained above and, where SIT is the control

technique used, modified to account for the proportion of matings taking place with sterile males.

Two situations were modelled: firstly the time taken to eliminate an isolated tsetse population, and secondly a situation where reinvasion could occur.

2.5. *Economic analysis*

The analysis is an economic, as against a financial analysis, in that, as far as possible, it includes all the costs incurred by the various economic agents affected (public and private sector). However, costs are valued at market prices without adjusting for externalities or market distortions. For this study, where community participation was not factored in as a significant component of any of the techniques, opportunity costs did not have to be estimated. For ITC, the cost of labour as reported by livestock keepers in Uganda was included.

Often the costs of operations against tsetse are cited per km^2 and compared without distinguishing between continuous control or elimination, and without specifying the total time period involved (Shaw, 2004). Usually the operation is costed either for a single year, or for elimination. In this analysis, particular attention has been given to timing, so that for the creation of fly-free zones an expenditure stream is fully costed. The stream starts with preliminary studies, proceeds to operations against tsetse and goes on to barriers and surveillance after tsetse have been removed.

When sums of money are spent or received in different years, the convention in economic or financial analyses is to 'discount' them; a process equivalent to removing compound interest from future sums of money. The 'discount rate' is the interest rate representing the minimum acceptable real return on money (that is, the return excluding inflation effects). In this study, a 10% discount rate was used, which is generally considered acceptable in livestock projects. 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 related lower 'return' considered acceptable for such projects. It could be argued that, with the current economic downturn, lower rates may also be appropriate in the livestock sector. However, this is less applicable to Africa; in Uganda real growth rates averaged 7% over the last 5 years. Therefore, a sensitivity analysis was conducted and results are provided for both 5% and 10% discount rates. Summary analyses are presented using 10%.

To provide a fair means for comparison for all techniques, whatever the preparation needed or time taken for deployment in the field, the 'year 1', for which no discounting was applied, was taken to be the first year of active field operations. All figures were discounted to their present value in this 'year 1'. Thus, because of discounting, expenditures incurred before year 1 (e.g. preliminary studies, tsetse surveys, tsetse rearing) increase in value while expenditures incurred after this decrease. All costs are expressed in US$. The preparatory years were given negative numbers, so the year before active field control was −1, the year before that −2, etc.

The cost calculations were all done using Microsoft Excel™ spreadsheets, without incorporating stochastic elements. This is because the costs of components of tsetse control tend to vary abruptly with different habitats and tsetse species or organisational contexts, rather than following a probability distribution. Instead, sensitivity analyses were conducted on those parameters considered most subject to variation.

Most of the cost data were initially collected in 2006 and based on local prices in Uganda and then converted to US$. The US$ is widely used as a standard and for planning purposes in the countries affected by tsetse and trypanosomiasis. The cost figures were selected from the upper end of likely costs so as to give them a longer period of applicability. Whilst the documents produced by PATTEC, in particular AfDB et al. (2004), were used as a basis for estimating the costs of pre-implementation overheads and studies, more recent information has been incorporated as appropriate, especially where there have been updates in our knowledge of the field costs of interventions, or where the technologies have evolved significantly. The costs of ITC have been updated based on field work from 2009 to 2011 in the project described in Kabasa (2007) and sensitivity analyses on the costs of trapping are based on Abila et al. (2007) and Esterhuizen et al. (2011). Throughout the study, a particular emphasis has been placed on the methodology, in order that such costs can be readily updated or the analysis adapted for other countries and contexts as required.

3. Results

3.1. *Tsetse population model outputs*

The main outputs of the tsetse population dynamics model were estimates of the time taken for each technique to eliminate tsetse in an area where the population is isolated. The results illustrated in Fig. 1 highlight how differently the control techniques perform, with the time taken to elimination with a trouble-free operation varying from 39 days for aerial spraying to 351 days if SIT were required to remove residual tsetse populations.

For the costings, the modelled timings under ideal conditions (Fig. 1) were all adjusted upwards (Fig. 2) to allow a margin for implementation. For traps, 180 days were allowed for setting them up, followed by 360 days of full deployment, as against the 216 modelled. For ITC, 360 days were costed for deployment, as against 145 modelled. For SAT, between 55 and 85 days were allowed, as against the 39 days modelled. For SIT, various suppression options were costed, with the shortest being 90 days using ITC or SAT, and SIT maintained for 540 days as against the 361 modelled. Entomological monitoring was estimated to continue for a full 3 years after the end of active control activities.

To investigate the situation for non-isolated tsetse populations, the tsetse model was set up for an area with invasion pressure on one side of the square-shaped 10,000 km^2 block. In the absence of a barrier, reinvasion would occur. Accordingly, costs were estimated for a 100 km-long by 10 km-wide barrier of either traps or ITC maintained for 3 years after the end of tsetse control

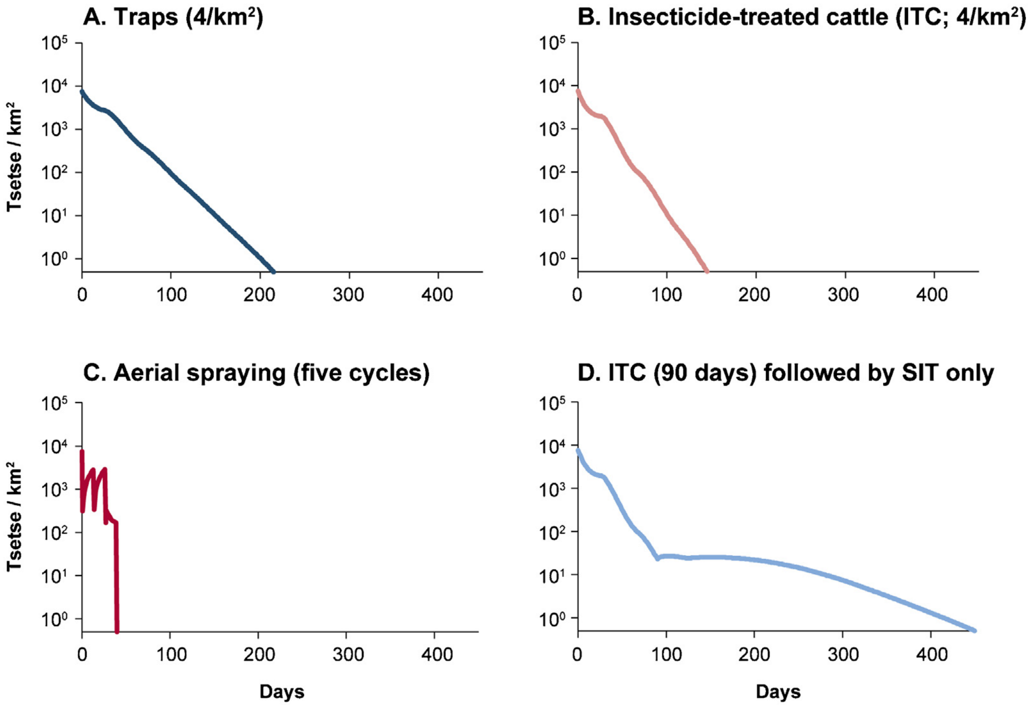

Fig. 1. Outputs of the tsetse population model showing the reduction in tsetse densities achieved by each technique applied to an isolated tsetse population under ideal conditions. Outputs were obtained from the tsetse population dynamics model described in Vale and Torr (2005); Kgori et al. (2006) and Torr and Vale (2011).

activities. Such a barrier was assumed to be capable of maintaining the remaining 9000 km^2 free of tsetse.

3.2. *Field costs for creating tsetse-free zones*

Fig. 2 shows the timings used for estimating the full costs of the different elimination techniques. The first four years (from −4 to −1) comprise preparatory activities, whilst 'year 1' marks the beginning of elimination activities.

3.2.1. *Artificial baits*

Deploying and servicing targets or traps relies on either community or employed labour. In our estimates, employed labour was used, and sensitivity analyses performed on the number of traps deployed and serviced per month, using the approach developed by Barrett (1997). The trap deployment was costed as being implemented over a period of six months, with two visits during the tsetse elimination operation to service the traps. Table 1 shows the costs for one year of deployment under different assumptions about trap density and number of teams required. The insecticide used is deltamethrin, and traps are serviced at 6-monthly intervals. Sensitivity analyses were also performed with respect to the cost of both traps and labour which assumed some low-cost labour inputs from the community and a greater sharing of vehicles.

The traps used in the baseline analysis cost US\$8 each, in line with those being used in Uganda and known to be effective for a year (Lancien and Obayi, 1993). However, cheaper traps have been developed (Abila et al., 2007). As shown in the table, halving the trap cost to US\$4 reduced the cost per km^2 by US\$16 at 4 traps per km^2. This works out at 8.2% of the field and 4.8% of the total costs of elimination before discounting. Although targets were not explicitly considered in this analysis, work by Lindh et al. (2009) has shown that an improved target design has the potential to increase field cost-effectiveness (as measured by tsetse killed per m^2 of cloth) by a factor of 10. Current work on micro-targets also offers great potential for cost reduction (Esterhuizen et al., 2011).

Table 1
Summary of cost calculations for trap deployment and servicing for one year.

Traps per km^2	Number of teams required	Cost per km^2 (US\$)
4	10	176
4	15	229
4 (reduced labour and vehicle cost)	10	158
4 (reduced labour and vehicle cost)	15	202
4 (reduced trap cost)	10	160
4 (reduced trap cost)	15	217
10	25	441
10 (reduced trap cost)	25	401
10	38	572
20	50	881
20	75	1145

Note: Underlying assumptions for calculating the number of teams required were that teams could deploy 500 new targets a month, and service 750. Initial deployment was allowed to take 6 months, so that one team could deploy 3000 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.

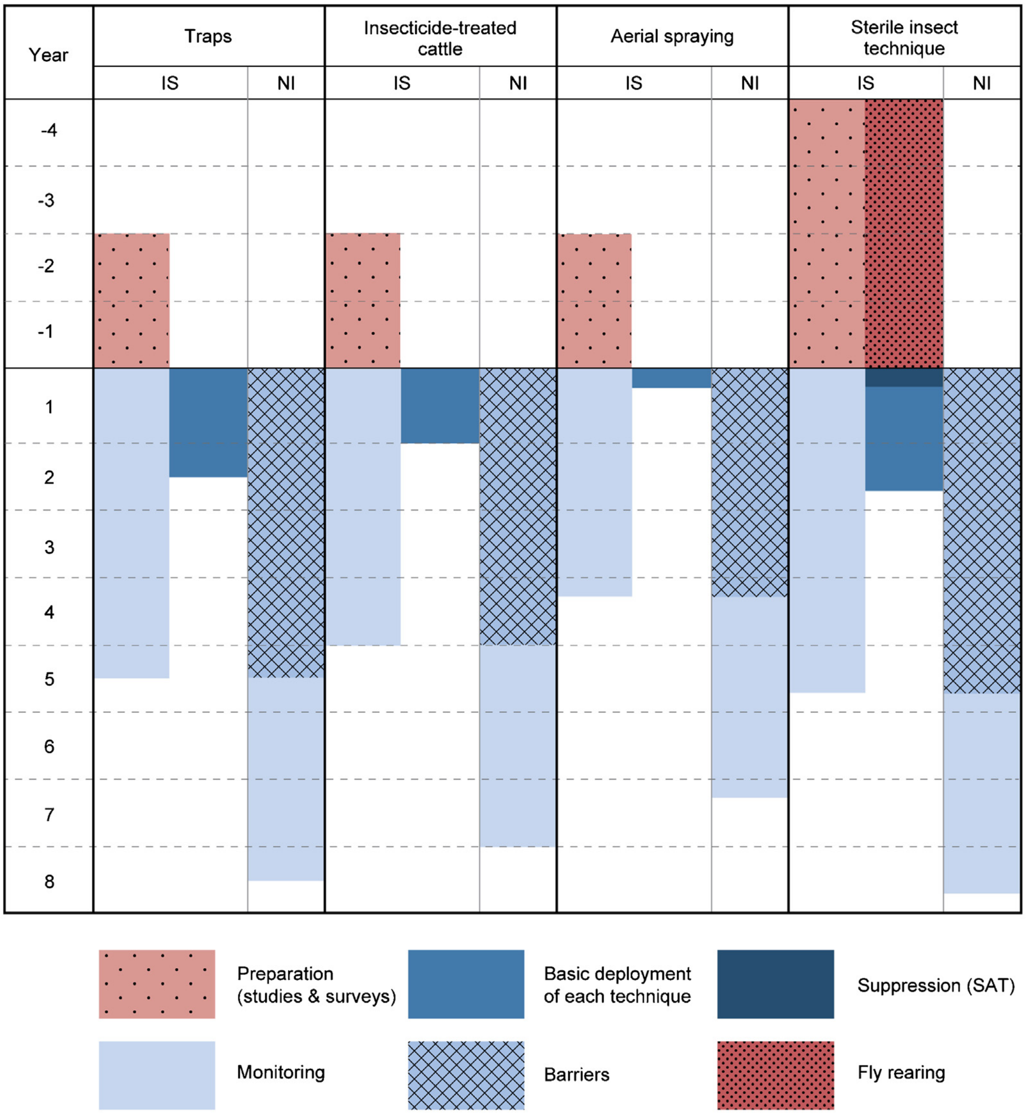

Fig. 2. Timings used in the cost calculations for various tsetse elimination techniques, assuming trouble-free operations targeting isolated tsetse populations under ideal conditions. IS: activities to be undertaken if the tsetse population is isolated. NI: supplementary activities to be undertaken if the tsetse population is not isolated.

Table 2 shows the costs for the eighteen months required for elimination: six months to deploy traps and a further year for the traps to remain in the field, so as to extend well beyond the period of 216 days that the tsetse model estimates as necessary for elimination (Fig. 1). After discounting at 10%, the costs ranged from US$251 for 4 traps per km^2 (against *morsitans* group flies such as *G. pallidipes*) to US$706 for traps at 10 per km^2 (against *palpalis* group flies such as *G. f. fuscipes*). Linearity was assumed within the range of trap densities used, although at high densities there might be labour savings, as the traps would be closer together and would therefore take less time to deploy. One factor that was not separately costed is the need to build and maintain access routes where the area to be treated is particularly isolated. This can increase costs substantially, very easily adding US$20 per km^2 (Udo Feldmann, personal communication).

3.2.2. *Insecticide-treated cattle*

Treating 4 large cattle per km^2 is considered sufficient to control or eliminate tsetse (Vale and Torr, 2004) and tsetse population modelling indicated that this would be effective unless there were areas over 3 km wide with no cattle (Hargrove et al., 2003; Torr and Vale, 2011). In order to allow a 20% margin, the calculations were based on treating 5 cattle per km^2. To find 5 large cattle per km^2, a minimum density of 10 would be needed. Furthermore, for effective control, an additional daily mortality greater than 3% must be imposed on the female vector population (Hargrove, 1988). Assuming a feeding interval of about 3 days then at least 10% of their bloodmeals must come from treated cattle to achieve control (Hargrove and Packer, 1993; Hargrove and Williams, 1995). Thus, at densities of over 50 cattle per km^2, 10% of cattle would need to be treated. Cattle densities in south-eastern Uganda vary considerably, from a few

Table 2
Summary of cost calculations for elimination in an isolated tsetse population using traps.

Year	Traps at 4 per km^2 (US$)	Low labour and vehicle cost traps at 4 per km^2 (US$)	Traps at 10 per km^2 (US$)	Discount rate (%)
−1 to −4	0	0	0	0
1	203	180	506	0
2	88	79	220	0
3–6	0	0	0	0
Cost per km^2 tsetse-free	291	259	726	0
Cost per km^2 tsetse-free	287	254	716	5
Cost per km^2 tsetse-free	283	251	706	10

small areas with fewer than 5 per km^2 to some localised high densities of over 250 per km^2 surrounding Entebbe and Kampala (Wint and Robinson, 2007). The bulk of the area falls within the density range 20–50 per km^2 with an average estimated at 43 per km^2, so baseline calculations were based on treatment of 5 cattle per km^2. An option of treating10 cattle per km^2 was also costed.

The costs of ITC were originally based on those given in Vale and Torr (2005) and Bourn et al. (2005) and have been updated in line with more recent experience. The costs vary considerably depending on how the insecticide is applied. At one end of the spectrum, the traditional pour-on formulation, despite the much lower prices charged for the product in Africa, remains the most expensive, at US$12 per animal treated per year. At the other end, restrictive application of insecticide costs less than US$0.72 for the insecticide. In Bourn et al. (2005) and Shaw et al. (2007), it was assumed that delivery and administration costs were a fixed percentage of the insecticide cost. Mulatu et al. (1999) found that costs for farmers' time and the costs of labour, transport and equipment added significantly to the total. In Uganda, the Stamp Out Sleeping Sickness programme calculated the insecticide cost per animal treated to be US$0.06 and found that in addition to project delivery costs, farmers invest time in bringing animals together, use resources such as ropes, and further invest in activities such as building and repairing crush-pens (A.H. Rannaleet, C. Waiswa and A. Shaw, unpublished data). Combining these delivery costs to those obtained from preliminary investigations on farmers' contributions under the Integrated Control of Neglected Zoonoses project, a cost of US$0.06 for insecticide and US$0.44 for delivery was estimated, coming to US$0.50 per dose, or US$6 for 12 doses. It is likely that the same delivery cost would also apply to the use of a pour-on.

Although the basic tsetse model predicted that ITC would eliminate tsetse in 145 days (Fig. 1), ITC was maintained for a year in these estimations. The costs increase linearly so that, at 5 ITC per km^2, the cost of spraying is US$30, and at 10 per km^2, it is US$60 (Table 3).

3.2.3. *Aerial spraying*

The costs for the elimination of an isolated tsetse population using SAT came to US$380 per 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. For SAT, all costs are incurred in year 1, so that no discounting was needed. Costs were based on those of the operations in Okavango Delta in Botswana (Kgori et al., 2006) with some price adjustments.

3.2.4. *Addition of a sterile insect technique component*

The costs of SIT for the 10,000 km^2 block are set out in Table 4. The cost per km^2 of releasing sterile males works out at US$758 when discounted at 10%. Because SIT operations span the longest period and many of the costs are incurred before the actual tsetse control operations start, the costs of SIT are affected by discounting to a greater extent than those of the other strategies.

Sensitivity analyses of the SIT costs were undertaken, to explore the possibility of reducing the cost, either by reducing the cost of flying time or the period of release. For example, although AfDB et al. (2004) allowed for 18 months of fly releases, the tsetse model predicts that if sterile males mate nearly as frequently as wild males and have slightly higher death rates, only 12 months would be needed. Thus the basic cost of US$758 would fall to US$683 if the release period were reduced from 18 to 12 months or to US$691 if the cost of flying time were reduced from US$700 to US$500 per hour.

3.3. *Non-field costs for creating tsetse-free zones*

3.3.1. *Administrative costs and overheads*

In this costing exercise, all supervision in the field and an appropriate share of the depreciation of capital items was included in the field costs for each technique, whereas the cost of maintaining and staffing a coordination office was calculated separately under the heading of 'administrative costs'. This cost was based on the estimates in AfDB et al. (2004). These included provisions for running a project coordination office, for support to government departments dedicated to tsetse and trypanosomosis control, for local meetings, for attendance at international meetings, for an annual review, and for provision of training and expert services. The costs were adjusted to reflect the duration of the preparation period, the main deployment phase of each technique and to allow for tsetse monitoring following deployment. Over the period analysed, this cost came to a total of US$29 per km^2 for interventions using traps, US$25 for ITC, US$20 for SAT and US$43 for SIT following suppression, with differentials reflecting differences in timing as illustrated in Fig. 2.

Table 3
Cost calculations for insecticide-treated cattle.

Insecticide/application method	Per animal treated per year (US$)	Treating 5 cattle per km^2 (US$)	Treating 10 cattle per km^2 (US$)
Deltamethrin spray, restricted application[a]	6	30	60
Traditional pour-on[b]	17	86	173

Notes: All costs are incurred in year 1, for which the discount factor used is 1 and thus no adjustment is needed.

[a] Figure of US$0.06 per cattle per month plus the cost of administration, bringing the cost up to US$0.50, or US$6 per annum.

[b] Pour-on cost based on 1 ml per 10 kg liveweight. 200 ml therefore treats 2000 kg, or 8 adult cattle, local price US$8 per 200 ml. The same cost of administration as for spraying is applied and figures rounded to nearest US$.

3.3.2. *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 (e.g. Adam et al., 2012). The AfDB et al. (2004) document also provided for the development of land cover and vegetation maps followed by surveys using traps for investigating tsetse population genetics. Once operations were underway, monitoring during the control activities and after they have been completed would be required (Fig. 2). After discounting at 10% this cost came to US$109 per km^2 for traps, US$105 for ITC, US$92 for SAT and US$123 km^2 for SIT.

3.3.3. *Other accompanying 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 AfDB et al. (2004):

- socio-economic: in this case a survey covering 8000 households undertaken over two months was proposed;
- environmental: surveys and monitoring was proposed to be undertaken in a sample of representative ecological zones, covering both the usage of insecticide and monitoring of land use after tsetse control;
- animal trypanosomosis: testing a sample of animals was proposed using standard trypanosome screening techniques, together with treatment of animals which tested positive for trypanosomosis;
- sleeping sickness: the cost of a standard survey and drugs for treatment of patients was included.

The cost of these surveys and studies came to US$60 per km^2, after discounting at 10%, and were the same whatever tsetse control method was used, corresponding to over a quarter of non-field costs (26–35%).

3.4. *Total cost of tsetse elimination*

3.4.1. *Isolated tsetse populations*

The total costs of the different intervention techniques under various assumptions are summarised in Table 5. The field costs show a very great range, with the various ITC options estimated to be the cheapest; ranging from US$30 to US$112 per km^2. These are followed by traps used against savannah species deployed at 4 per km^2 (US$251–283), then SAT at US$380 per km^2, followed by 10 traps per km^2 against *G. fuscipes* (US$706). The addition of an SIT component is estimated to cost US$758.

Table 4
Summary of cost calculations for the breeding and release of sterile males to target an isolated tsetse population over an area of 10,000 km^2.

Year	Fly rearing			Fly release (US$)	Totals (US$)	Discount rate (%)
	Capital items (US$)	Recurrent items (US$)	Share for project (%)			
−4	7,760,400	835,600	25	0	2,149,000	0
−3		835,600	25		208,900	0
−2		835,600	25		208,900	0
−1	32,000	835,600	25		216,900	0
1		835,600	100	1,233,500	2,069,100	0
2	211,000	835,600	50	1,233,500	1,756,800	0
3–6	0	0	0	0	0	0
Total cost for 10,000 km^2					6,609,600	0
Cost per km^2 tsetse-free					661	0
Cost per km^2 tsetse-free					705	5
Cost per km^2 tsetse-free					758	10

Source: Figures adapted from AfDB et al. (2004), based on one insectary sequentially providing sterile male tsetse for four 10,000 km^2 blocks (hence the variable share for the project).

Note: Using the discounting process, costs incurred before implementation starts (with fly releases in year 1) are higher than their nominal value (Section 2.5).

Table 5
Summary of the costs for creating a tsetse-free zone for isolated tsetse populations under ideal conditions (US$ per km^2 tsetse-free, discounted at 10%).

Intervention technique	Field cost	Studies	Admin	Total
Traps				
Savannah tsetse species (4 per km^2)	283	170	29	482
G. fuscipes (10 per km^2)	706	170	29	905
Savannah + fewer studies	283	85	29	397
Savannah tsetse species + reduced field costs	251	170	29	450
ITC				
Pour-on (5 per km^2)	112	165	25	302
Spray (5 per km^2)	35	165	25	225
Restricted application (5 per km^2)	30	165	25	220
Restricted application (10 per km^2)	60	165	25	250
Restricted application (5 per km^2) + fewer studies	30	82	25	137
SAT				
Basic SAT	380	152	20	552
SAT + fewer studies	380	76	20	476
SIT				
Addition of SIT alone	758	–	–	758
SIT + 90 days ITC (restricted, 5 per km^2)	766	184	43	993
SIT + 360 days ITC (restricted, 5 per km^2)	788	194	48	1030
SIT + 4 cycles SAT	1062	184	43	1289
SIT + 5 cycles SAT	1138	184	43	1365

The costs of administration (between US$25 and US$43) and studies (between US$165 and US$194) add considerably to the field costs. For some methods, the effect of reducing the costs of the studies was also evaluated. However, a reduction of 50% in the cost of studies does not alter the ranking or the absolute differentials between techniques.

The breakdown of field costs is provided in Table 6. What is striking is the highly variable share of the 'core components' in total field costs, ranging from 32% for traps, 60% for ITC and 82% for SIT to 96% for SAT.

In Table 7 the breakdown of total costs is given. Because of the high costs for planning, administering and monitoring elimination programmes, adding these overheads increases costs substantially. The proportional effect is particularly marked for the techniques with lower field and lower core costs. For the purposes of comparison for SIT the cost was based purely on the addition of SIT and does not include the suppression technique, thus somewhat overestimating the ratio of overheads to field costs. With this in mind, the percentage of overheads in total costs ranges from 25% for the addition of an SIT component to 85% for ITC at 5 per km^2.

Table 6
Breakdown of field costs (undiscounted figures).

Component of field costs (%)	Traps	ITC using RAP[a]	SAT	Addition of SIT
Core component 1[b]	9.0	12.0	92.0	79.9
Core component 2[c]	21.8	48.1	4.2	1.9
Depreciation: vehicles and other items	21.9	3.1	0.7	2.3
Vehicle running	9.2	6.4	0.9	7.9
Other running	0.4	7.5	0.0	0.6
Staff salaries	13.5	17.2	1.6	7.3
Staff allowances	14.4	5.7	0.6	0.1
Paid labour	9.8	0.0	0.0	0.0
Total	100.0	100.0	100.0	100.0

[a] RAP refers to restricted application.

[b] For traps: traps; for ITC: insecticide; for SAT: insecticide and flying time; for SIT: cost of producing sterile males and flying time.

[c] For traps: herbicide, insecticide and odours; for ITC: livestock keepers' time and their other inputs; for SAT: airport maintenance and access; for SIT: airport maintenance.

3.4.2. *Non-isolated tsetse populations*

Tables 8 and 9 show how the costs might change for non-isolated tsetse populations. The cost for the barriers varies greatly depending on whether traps or ITC are used, the former being far more costly (Table 8). Smaller variations reflect the extent to which the barrier complements the technique already being used and at what density the ITC are deployed.

Table 9 goes on to show how the addition of barriers affects total costs. The last column gives the ratio of the cost for a non-isolated (NI) area to an isolated (IS) area, as costed in Table 5. Where traps are used as a barrier, the cost increases by between 29% and 57%. This figure would be even higher if 20 traps per km^2 barriers were considered for *G. fuscipes*. For ITC barriers the cost increase is between 12% and 30%.

Table 7
Breakdown of total costs (undiscounted figures).

Component of total costs (%)	Traps at 4 per km^2	ITC using RAP[a] at 5 per km^2	SAT	Addition of SIT
Core components	17.9	8.8	67.3	61.3
Other field costs	40.3	5.8	2.7	13.7
Entomologicial studies	23.2	47.2	16.0	13.9
Other studies	12.5	26.7	10.6	6.5
Administration	6.1	11.5	3.4	4.5
Total	100.0	100.0	100.0	100.0
Ratio of overheads/field costs	0.7	5.8	0.4	0.3
Field costs/total costs (%)	58.2	14.6	70.0	75.0

[a] RAP refers to restricted application.

Table 8
Cost calculations for barriers (US$ per km^2).

Year	Insecticide-treated cattle at 10 per km^2 used as a barrier with						Traps at 8 per km^2 used as a barrier with				Discount rate (%)
	ITC at 5 per km^2	ITC at 10 per km^2	Traps	SAT	SIT	SIT + full ITC	Traps at 4 per km^2	Low cost traps at 4 per km^2	SAT	SIT	
−4 to −1	0	0	0	0	0	0	0	0	0	0	0%
1	30	60	60	60	60	60	229	202	458	458	
2	62	123	62	62	62	62	458	404	458	458	
3	64	127	64	64	64	64	458	404	458	458	
4	65	131	65	16	65	65	458	404	115	458	
5			34		50	50	229	202		344	
6						26					
Cost per km^2 of barrier	221	441	284	202	301	327	1832	1616	1489	2176	0%
Cost per km^2 tsetse-free	25	49	32	22	33	36	204	180	165	242	
Cost per km^2 of barrier	203	406	261	191	274	295	1665	1468	1409	1988	5%
Cost per km^2 tsetse-free	23	45	29	21	30	33	185	163	157	221	
Cost per km^2 of barrier	188	375	241	181	252	268	1524	1345	1339	1832	10%
Cost per km^2 tsetse-free	21	42	27	20	28	30	169	149	149	204	

Note: For all strategies the full barrier needs to be in place throughout the elimination phase and is assumed to be maintained exactly three full years afterwards as shown in Fig. 2. For ITC and traps, the barrier consists of additional baits alongside those in place for the initial tsetse control phase and then twice the number per km^2 during the barrier phase. The number of cattle treated in ITC barriers increases at 2.9% per annum in line with the cattle population. For SAT and SIT either a trap or an ITC barrier is added. At 8 per km^2 the trap barrier is suitable for savannah flies only. 1000 km^2 of barrier is required for every 9000 tsetse-free km^2.

3.5. *Costs of continuous control operations*

The costs of continuous control operations are summarised in Table 10. The cost of each approach was calculated individually, to provide a basis for comparison with the costs of creating fly-free zones. In a real operation, a combination of approaches over time would probably be used. Three factors have a great impact on the results: the length of the period analysed; the discount rate selected; and the likely relative impact of control versus elimination on the effect of the disease, which is also linked to the scale of the operation.

Three tsetse control scenarios were analysed, with traps and ITC being applied annually and SAT at 3-yearly intervals. For purposes of comparison, trypanocide prophylaxis of cattle based on 4 doses of isometamidium per annum was also costed out for two cattle populations densities, one approximating to the average density in the area (about

Table 9
Summary of the costs for non-isolated tsetse populations subject to invasion pressure from one side (US$ per km^2 tsetse-free, discounted at 10%).

Intervention technique + barrier	Costs					Ratio[a] NI/IS
	Field cost	Barriers	Studies	Admin	Total	
Traps + ITC or trap barrier						
Savannah tsetse species (4 per km^2) + trap barrier (8 per km^2)	314	169	216	43	742	1.49
G. fuscipes (10 per km^2) + ITC barrier (10 per km^2)	784	27	216	43	1070	1.16
Savannah (4 per km^2) + trap barrier (8 per km^2) + fewer studies	314	169	108	43	634	1.57
Savannah (4 per km^2) + trap barrier (8 k per m^2) + local labour	279	149	216	43	687	1.48
ITC + ITC barrier						
Restricted (5 per km^2) + ITC barrier (10 per km^2)	33	21	209	38	301	1.23
Restricted (10 per km^2) + ITC barrier (20 per km^2)	67	42	209	38	356	1.30
Restricted (5 per km^2)+ ITC barrier (10 per km^2) + fewer studies	33	21	105	38	197	1.30
SAT + ITC or trap barrier						
Basic SAT + trap barrier (8 per km^2)	422	149	192	31	794	1.34
Basic SAT + ITC barrier (10 per km^2)	422	20	192	31	665	1.12
Basic SAT + ITC barrier (10 per km^2)+ fewer studies	422	20	96	31	569	1.13
SIT + ITC or trap barrier						
SIT + ITC suppression + ITC barrier (10 per km^2)	851	28	233	60	1172	1.16
SIT + full ITC + ITC barrier (10 per km^2)	876	30	248	66	1220	1.19
SIT + SAT suppression + trap barrier (8 per km^2)	1180	204	233	60	1677	1.29
SIT + SAT suppression + ITC barrier (10 per km^2)	1180	28	233	60	1501	1.15
SIT + full SAT + ITC barrier (10 per km^2)	1264	28	233	60	1585	1.15

Notes: Administrative overheads and studies have been adjusted respectively to account for the extra cost of supervising maintenance of the barriers and the longer period of entomological monitoring required within the barrier area and, at a lower intensity, in the fly-free area. Trap barriers are suitable for savannah flies only. For *G. fuscipes* a barrier of at least 20 per km^2 would be needed.

[a] Ratio NI/IS refers to the ratio of the cost for a non-isolated (NI) population as costed here to an isolated population (IS) as costed in Table 5.

Table 10
Cost of continuing interventions to control tsetse and trypanosomosis (US$ per km^2).

	Traps at 4 per km^2	Traps at 10 per km^2	ITC at 5 per km^2 increas-ing with cattle popula-tion	SAT	Trypanocide prophylaxis for 15 bovines per km^2	Trypanocide prophylaxis for 45 bovines per km^2
Annual cost	202	505	30[a]	380	105[a]	315[a]
Administrative overheads (%)	10	10	5	20	5	5
Total annual cost	222	556	32	456	110	331
Frequency applied	Annually	Annually	Annually	3-yearly	Annually	Annually
Present values over 10 years[b]						
0% discount rate	2444	6111	401	1824	1405	4214
5% discount rate	1938	4845	314	1698	1098	3295
10% discount rate	1588	3969	254	1590	888	2665
Present values over 20 years[b]						
0% discount rate	4666	11,666	894	3192	3128	9383
5% discount rate	2991	7478	545	2771	1906	5718
10% discount rate	2114	5285	368	2442	1287	3862
Present values over 30 years[b]						
0% discount rate	6888	17,221	1549	5016	5421	16,263
5% discount rate	3638	9095	733	3977	2566	7697
10% discount rate	2317	5792	426	3258	1492	4477

[a] These estimates increase at 2.9% per annum in line with the growth rate calculated for the cattle population (Wint et al., 2011).

[b] For comparability with the creation of fly-free zones, there is initial application in 'year 1' followed by 10, 20 or 30 further years of control as stated in the table.

45 per km^2) and one midway in the cattle population band found in some of the less densely populated zones of the study area (15 per km^2). The cost was based on US$1.80 for an adult dose, with the average bovine weight 0.7 of the adult weight, so the dose would be US$1.25 to which US$0.50 was added for administering the drug, a low price based on the high number of interventions to be undertaken. The total price would thus be US$7 per head per annum. As for the elimination scenarios, Table 10 shows a wide range for the costs of control.

4. Discussion

The scenarios analysed in this paper are based on field experience and realistic operational planning. However, as in any modelling effort, numerous assumptions and simplifications have had to be made. In order to assess the impact of these assumptions on the results, sensitivity analyses were conducted, and a wide range of options for controlling or eliminating tsetse flies was costed. The costings presented here refer to trouble-free and delay-free operations. Evidence from experiences such as in the Okavango (Kgori et al., 2006) and Zanzibar (Vreysen et al., 2000) indicate that achieving and sustaining elimination often requires several attempts and that anticipated timings are frequently exceeded. Here, allowances have been made for some delays and figures – especially timings – were generously accounted for. The complexity of tsetse behaviour in various tsetse habitats and their interactions with their hosts are such that the creation and maintenance of fly-free zones is a very complex task. Furthermore, it is difficult to be categorical about the length of time for which barriers would be needed; the 3 years estimated here is probably on the low side. The figures thus represent probable orders of magnitude and an appropriate baseline for differentiating among techniques but are unlikely to be an accurate basis for predicting total operational costs in different situations.

In order to provide baseline costs and relative orders of magnitudes for the different techniques, each one has been costed individually. In practice, in the field, a successful operation would often involve a combination of approaches. These would always include treating the disease in humans and usually in livestock. Another example where integrated control would be indicated is the deployment of traps in areas where there are insufficient cattle to support ITC. It should also be noted that, whilst outside the scope of this paper, there are important public/private good issues in tsetse control. The techniques vary greatly in terms of technical complexity and the extent to which they can be expected to be adopted by livestock keepers. In addition to treating their livestock with trypanocides, livestock keepers often use ITC to control ticks as well as tsetse, and community involvement in trapping has been tried in a range of situations (Swallow et al., 1995; Dransfield and Brightwell, 2004).

Bearing these caveats in mind, and looking first at the comparisons between techniques, the results presented here are in line with the ranking, range and cost-breakdowns found by Barrett (1997), Brandl (1988) and Putt et al. (1980). They also fall in the range recently calculated for the use of targets in Kenya in an eight year programme, with overheads over the period estimated at US$140 and field costs ranging between US$114 and US$190 per km^2 (McCord et al., 2012). In addition, as compared to those previous studies, it is clear that the field costs of intervention techniques have generally fallen, as entomological research has improved their efficiency. This trend is particularly marked for ITC, but also applies to SAT and traps/targets. Since 2006, the reference year for most of the cost data used in this paper, the price inflation for the components of tsetse control has been lower than the overall rate estimated for Uganda. If expressed in Ugandan

Shillings, government salaries for entomological staff and drivers have increased by 30%, fuel prices by 40%, whilst, as discussed above, more cost-effective stationary baits have been developed. Meanwhile the Ugandan shilling in 2011 averaged 2554 per US$, 44% more than its rate in 2006, and has remained at a similar level in 2012. These dynamics emphasise the difficulties of standardising on a particular currency, since in US$ terms, the costs presented here have changed little, whereas in Ugandan shillings, there have been substantial increases and, using 2011/2012 exchange rates, costs in Ugandan shillings should be increased by 30–40%.

The costings highlight a number of technical constraints. In terms of logistics and organisation, traps are the most demanding of the techniques examined. This also implies that sustaining operations over the long term, for barriers or continuous control operations, would be challenging. ITC relies on the presence of cattle, and livestock keepers are often already used to spraying their cattle against ticks. A minimum cattle density of 10 per km^2 is required. While there are some small areas within the case study area where this is not the case (so that another technique would be needed), in general this density is comfortably exceeded. While the study area does not contain the type of rugged terrain that would preclude the use of SAT and has dense human populations, the issue of the difficulty of penetrating thick vegetation may be relevant in some locations (Allsopp and Hursey, 2004). SIT involves at least one other technique for suppression and possibly barriers.

The costs of the accompanying studies and overheads needed to plan and execute elimination efforts also merit further study. These are very substantial costs which, for low density traps/targets, nearly outweigh the actual field costs and, for ITC, greatly exceed field costs. Standard protocols for cost-effective accompanying investigations are very much needed.

5. Conclusions

The methods presented in this paper have been developed by using south-eastern Uganda as a case study, but they have been set out so that, in the future, different assumptions and more accurate or more recent information can be readily and flexibly incorporated. This will enable new field experiences and changing prices to be accounted for, and different geographical locations to be investigated. Ultimately such cost considerations need to be considered alongside potential benefits, and work on this is ongoing, building on Wint et al. (2011).

The approach of full costing was used, which enables a comprehensive assessment of all direct and indirect costs of interventions to be made. While the core costs of each intervention technique are essential indicators of efficiency, they can account for only a small proportion of costs. Also, the share of core costs in total costs varies greatly (from less than a tenth to over two thirds) so that core costs alone are not sufficient for ranking costs. Estimates of the likely total investments required are vital for judicious financial planning and decision-making. Full costing is also essential when trying to compare costs to potential benefits.

Over three decades ago Jordan (1978) stated that: “The success of attempts to control African trypanosomosis afflicting both men and animals through the destruction of the tsetse vector depends on a realistic assessment of human and ecological factors in infested regions. The complete eradication of tsetse is at present possible only in limited areas, and elsewhere the advantages of periodic control campaigns have to be weighed carefully against their cost.” This observation is still valid. However, since 1978 the range of techniques at our disposal has increased, they are more environmentally benign, and their field costs have fallen significantly, so much so that ongoing control using some of the cheaper options is competitive with the cost of elimination over 20 years and, depending on the technique and discount rate used, even over 30 years. Thus, it should be considered whether setting elimination as a goal from the outset is the ideal strategy, or whether, especially in areas with strong reinvasion risk, control operations should be a starting point. The issue is also reflected in the advocated phased conditionality approach to tsetse elimination (Feldmann and Parker, 2010). However, continuous control, depending on the scale and intensity, is likely to be less efficient at reducing tsetse numbers, and hence the incidence of trypanosomosis, than elimination. The scale of the operation would be a major consideration in this. SAT is necessarily applied on a large scale, whereas ITC and traps can be applied on a smaller scale but are less effective in smaller areas (Hargrove, 2004; Vale and Torr, 2004).

Thus, by bringing together estimates for both control and elimination for all the techniques currently in use, very considerable differences in both cost and timing are revealed. These are crucial considerations for planners to factor in alongside technical and operational constraints.

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