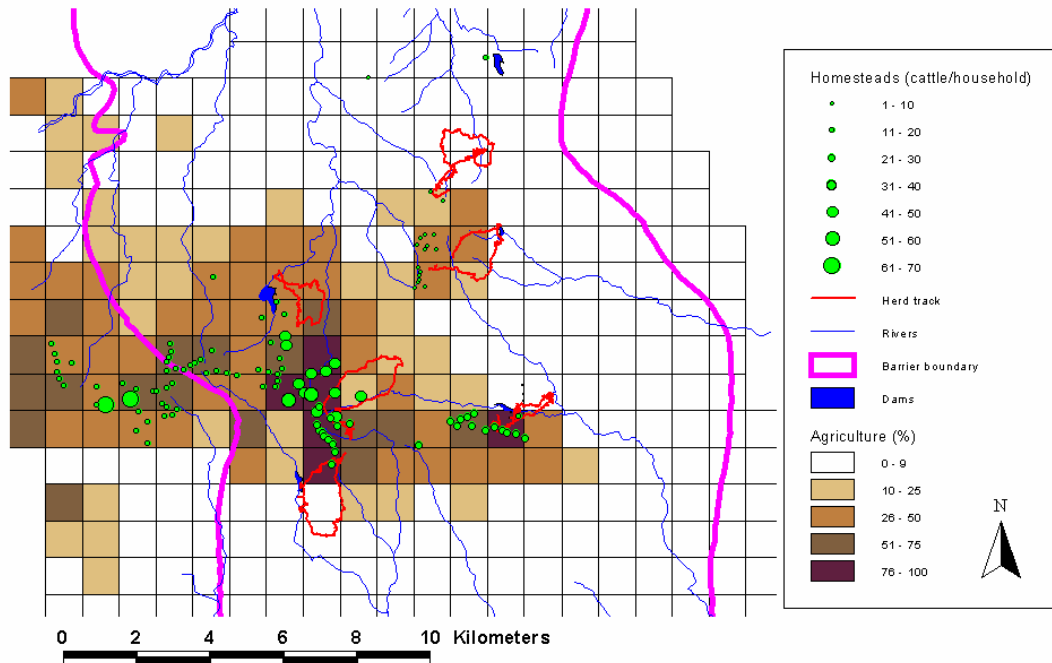


FINAL TECHNICAL REPORT

Cattle management practices in tsetse-affected areas.

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Executive summary

Project Purpose

This project aimed to develop cost-effective, appropriate and sustainable strategies to control animal diseases that affect the livelihoods of the poor. Tsetse flies infest over ~10 million km² of Africa where they transmit trypanosomiasis in man and domestic livestock. The use of insecticide-treated cattle is, generally, not only the cheapest vector-control method but is also amenable to communities and individual livestock owners. The effectiveness of this technique is variable, however, and the cause of this variation is unknown. This project carried out technical and socio-economic studies to identify variables affecting the effectiveness and acceptability of the technique.

Outputs and activities

The project aimed to:-

- Establish quantitative relationships between cattle density/distribution and cattle-tsetse contact in Zimbabwe and Tanzania and;
- Produce recommendations on the suitability of insecticide-treated cattle to control tsetse in the three project areas in particular and tsetse-infested areas of Africa in general.

To achieve this, various entomological, socio-economic and ecological studies were undertaken.

Entomology.- Studies were made of the attraction, landing and feeding responses of tsetse on herds of cattle. These studies showed that the numbers of tsetse contacting a herd increased as a curvilinear function of a herd's mass. The number of attracted tsetse that subsequently fed, and hence contacted cattle, was a function of the herd's composition but, in general, ~50% of attracted tsetse fed.

Socio-economics.- Studies were made of cattle ownership, management practices and farmers' perceptions of problems associated with owning livestock in four tsetse-affected areas where one of the following farming systems predominated: mixed crop-livestock farming, traditional pastoralism, small-scale dairy production and commercial ranching.

Ecological Modelling.- Socio-economic and entomological data were incorporated into simulation models describing the relationship between the distribution of insecticide-treated cattle and the population dynamics of tsetse. The models were validated, using existing data from three tsetse control operations, and then used to predict the outcomes of various tsetse control interventions being considered by farmers and institutions in Zimbabwe and Tanzania. The analyses indicated that important determinants of the effect of insecticide-treated cattle were: patchiness of human/cattle settlements, grazing ranges of the cattle, herd sizes and the size of the control area. These factors were strongly influenced by the underlying cattle management systems and the distribution of natural resources such as water and pasture.

Dissemination.- Project findings were disseminated via reports, workshops in Zimbabwe and Tanzania, presentations at international meetings and papers in international journals. The

models developed by this project were used in designing proposals for EU-supported tsetse control schemes in the Tanga Region of Tanzania.

Contribution to development

The tsetse-affected regions of Africa are home to ~260 million people. For livestock owners in these areas, the cheapest technical option for controlling tsetse is to treat their cattle with insecticide. Since the efficacy of this technique is variable, livestock owners are forced to gamble limited resources on an uncertain outcome. This project provided a more rational basis for predicting the outcome of using insecticide-treated cattle to control tsetse. Accordingly, the findings have enabled communities of livestock owners to plan community-based strategies for controlling trypanosomiasis.

Background

Tsetse flies infest over 11 million square kilometres of Africa where they are vectors of trypanosomiasis in man and domestic livestock. Animal trypanosomiasis is a major constraint to agricultural production in many of the more deprived areas of Africa, preventing or greatly reducing the productivity of animals.

In Zimbabwe, tsetse could occupy about half the country but a combination of a rinderpest epidemic in the last century and tsetse control operations this century has reduced the extent of the disease to <10% of the country, to an area of *ca.* 30 000 km² in northern Zimbabwe (Lovemore, 1994). To maintain this low level of disease, the Zimbabwe Tsetse and Trypanosomiasis Control Branch (TTCB) conducts continuous control operations costing *ca.* Z\$60 million/year.

In 1994, Tanzania was estimated to have >13 million cattle, making it the third largest national herd in Africa, with 99% of the cattle being owned by smallholder livestock keepers (NRI, 1996). The largest concentrations of cattle are in the arid and semi-arid regions in the north and centre where there is a strong tradition of pastoralism. The potential of these areas is severely limited by both tick and tsetse-borne diseases; it is estimated that tsetse still infest *ca.* 60% of the country. Currently, there are no large-scale government-funded control operations and, instead, disease management is carried out by individuals and communities.

Bait technology

Trypanosomiasis is controlled either directly through the use of trypanocidal drugs, or indirectly by controlling tsetse and thereby breaking the disease transmission cycle (Jordan, 1986). In the last decade, 'bait technology' has become the preferred method of tsetse control in most African countries (Green, 1994). Essentially, this technology controls tsetse by luring adult flies to traps or insecticide-treated targets which are usually baited with odours mimicking a host. The attracted flies are either retained by the trap or contact the target and pick up a lethal dose of insecticide and die. The low reproductive rate of tsetse means that a low density (*ca.* 4/km²) of evenly-spaced baits can eradicate tsetse populations within two years (Vale, 1993; Willemsen, 1991; Dransfield *et al.*, 1990). In areas where cattle and tsetse co-exist, a third form of bait technology is frequently used whereby cattle are treated with a pyrethroid insecticide such as deltamethrin. Work originally carried out in Zimbabwe showed that tsetse alighting on cattle treated with deltamethrin dip were killed (Thomson, 1987) and large-scale trials in Zimbabwe (Thompson *et al.*, 1991), Zambia (Chizyuka and Liguru, 1986), Tanzania (Fox *et al.*, 1991), Kenya (Stevenson, 1991), Burkina Faso (Bauer *et al.*, 1992) and Ethiopia (Leak *et al.*, 1995) have demonstrated the effectiveness of this approach.

Bait technology has become the preferred control option throughout Africa because it is generally the cheapest method (Barrett, 1994), it is environmentally benign (Vale, 1993) and it is amenable to community-based approaches to control. This latter point is particularly important due to the funding and infrastructure constraints faced by most countries with tsetse-infested areas.

Currently in Zimbabwe, tsetse are controlled through the deployment of *ca.* 60 000 targets combined with a barrier of 200 000 insecticide-treated cattle along the NE border with

Mozambique. In Tanzania, insecticide-treated cattle have been more widely employed in attempting to control tsetse. The most successful application of this technology in Tanzania has been in the Kagera region where tsetse have been virtually eradicated from large proportions of Bukoba and Karogwe Districts and the recorded annual incidence of animal trypanosomiasis in the region has declined from 193000 in 1991/92 to 2383 in 1996/97 (Okali *et al.*, 1997).

There are instances, however, where the use of bait technology has been less successful. In the Doma region of Zimbabwe, tsetse were not controlled by targets as effectively as expected and in Mudzi district a barrier of treated-cattle did not prevent tsetse invading from uncleared areas in Mozambique (Warnes *et al.*, 1999). In the Tanga region of Tanzania, the application of insecticide-treated cattle at Mkwaja Ranch in the late 1980s led to a decline in tsetse numbers and trypanosomiasis but since 1991 the disease situation has not continued to improve, despite continued insecticide and chemoprophylactic treatment of animals, and the use of insecticide-treated targets.

The technology based on using traps and targets is underpinned by a large body of theoretical knowledge and practical experience (see review by Green, 1994). Consequently, there is generally a rational basis for predicting the efficacy of control operations and for identifying reasons for failure where this occurs. For insecticide-treated cattle however, the technology has developed more empirically and currently there is little information on even such basic matters as the density and distribution of cattle required to effect control, or how this is affected by variables in cattle and tsetse populations and local ecology such as densities of game and vegetation. Consequently, the basis for rational planning and management of tsetse control based on this approach is poor. It is particularly important to establish the limits of the technique since donors are vigorously promoting the use of this technology for use by resource-poor farmers and communities. There is thus an urgent need for quantitative data on the effectiveness of dipped cattle as baits which can be combined with existing tsetse population models to develop rational strategies to control tsetse.

Social science and tsetse control

The need for socio-economic input into tsetse research and control strategies has been increasingly emphasised in recent years (Salmon & Barrett, 1994; RTTCP, 1996; Barrett & Okali, 1997), particularly in response to the greater involvement of local communities in tsetse control, which is now being promoted by donors and governments alike. For example, the EU regional tsetse programmes (RTTCP, FITCA) stress the need for beneficiary involvement in both planning and implementation of tsetse and trypanosomiasis control strategies. In a DFID-funded study (R6553) of community involvement in tsetse control using trap and target technologies, a number of locations were visited and research and control operations studied. It was found that in many cases social science inputs into these operations was minimal or even non-existent, and the effectiveness of technologies was therefore being compromised because of the failure to appreciate the full significance of socio-economic issues.

With regard to the insecticide-treated cattle technique, social science methodologies can address both technical and socio-economic questions. Firstly, the successful use of insecticide-treated cattle depends upon adequate tsetse-cattle contact, and the extent of this will be determined *inter alia* by interactions between spatial and temporal distributions of tsetse and cattle. In this project, natural and social scientists examined the dynamics of cattle

density, movement and distribution and the effect of these on tsetse-cattle contact in mixed crop/livestock farming systems in Zimbabwe and Tanzania. Secondly, the effective application of the technique requires knowledge of cattle management practices and, if it is to be taken up by farmers, the relevance of tsetse control in general and this technique in particular to their specific circumstances also needs to be identified. These issues were investigated and the findings will be used to produce a guide defining measurable parameters that will affect the likely efficacy of using insecticide-treated cattle to control tsetse in different locations.

In Zimbabwe there has been no socio-economic investigation into the apparent failure of the technique to prevent reinvasion from uncleared areas of Mozambique, although it has been suggested that the heterogeneous spatial and temporal distribution of cattle throughout the area played a significant role in reducing the effectiveness of the control method. Further investigation of herd composition and daily and seasonal management practices is required if this is to be clarified. In addition, if the technique is to be appropriate for use by farmers in areas such as Tanzania where tsetse control is not centrally organised, an understanding of their current management practices, their existing strategies for trypanosomiasis and tick control, and their perceptions of the benefits/relevance of such control in relation to other priorities, is essential in order to determine the appropriateness of insecticide-treated cattle as a control strategy.

The efficacy of an insecticide-treated animal for controlling tsetse is a function of the number of flies that contact the animal for sufficient time to pick up a lethal dose of insecticide. Cattle distribution will have a major impact on tsetse-cattle contact; the increased dose of odours produced by grouping animals increases the numbers of tsetse attracted in a curvi-linear manner (Hargrove *et al.*, 1996) and variation in the daily and seasonal distribution of animals will affect the probability of tsetse contacting a treated animal. This project investigated these matters using a combination of entomological and social science methodologies and the results were used to predict the technical and social feasibility of using insecticide-treated cattle under different livestock-management regimes.

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Project purpose

The purpose of this project was to develop cost-effective, appropriate and sustainable strategies to control animal diseases which affect the livelihoods of the poor.

Tsetse flies infest over 10 million km² of Africa where they are vectors of trypanosomiasis in man and domestic livestock. In many tsetse-affected countries, the use of insecticide-treated cattle to control the vector is not only one of the cheapest methods of control but is also one of the few techniques that is potentially amenable to communities and individual livestock owners. However, the results of using this technique have been variable: in some areas (e.g. Kagera region, Tanzania) tsetse have been virtually eradicated whilst elsewhere (e.g. Mudzi district, Zimbabwe; Tanga region, Tanzania) the technique has been less successful. The cause of this variation is unknown. Accordingly, this project carried out technical and socio-economic studies of variables that determine the effectiveness and acceptability of insecticide-treated cattle in controlling tsetse, and hence trypanosomiasis. The project was particularly concerned with the application of these technologies for the benefit of local communities of poor farmers in Zimbabwe and Tanzania.

The project aimed to achieve these outputs by undertaking the following research:-

- Field studies to measure the attraction, landing and feeding responses of tsetse on herds of cattle.
- Development of predictive model to describe relationship between cattle distribution, tsetse-cattle contact and tsetse population dynamics.
- Assessment of cattle ownership and management practices and farmers' perceptions of livestock problems in tsetse-affected areas.

In the present report, the activities and outputs are reported in three separate sections. First, we report on experimental studies of the responses of tsetse to herds of cattle. Second, we describe the development and validation of predictive models to describe the effects of baits on tsetse populations. And in the third and final section, we report on socio-economic studies of various sites in Zimbabwe and Tanzania and the application of the models to predict the outcome of proposed tsetse control measures.

The effects of herding practices on the attraction and feeding responses of tsetse.

Summary

In Zimbabwe, studies were made of the feeding responses of *Glossina pallidipes* Austen and *G. m. morsitans* Westwood to groups of cattle. The groups comprised mixtures of adult and young animals arranged in groups of 2-12 animals. The number of tsetse attracted to, and subsequently feeding on, the cattle was assessed using an incomplete ring of electric nets which surrounded the cattle. The numbers of tsetse attracted to the group increased as an exponential function of the liveweight of the group; groups of 4 or 12 oxen respectively attracted ~2 times or ~4 times as many tsetse as a single ox. The proportion of the attracted tsetse that fed successfully was dependent on the composition of the group. Groups composed entirely of adults or young animals produced feeding rates of ~40% and ~10% respectively. A mixed group of young and adults produced a feeding rate of ~40% as long as at least one animal was an adult. It is inferred that in a mixed group of hosts, tsetse locate and feed preferentially on the adults within the group. Placing cattle in a kraal reduced feeding success by ~15% if the kraal was constructed with a roof and a solid wall. The presence of a herdsman reduced the numbers of tsetse feeding if the herdsman accompanied a single ox but not if he attended a group of four oxen. A review of the literature suggests that a single adult ox treated with insecticide kills about as many tsetse as an insecticide-treated target baited with artificial attractants. Assuming that such targets produce a daily mortality of 2%/km², then it is argued that a herd of cattle with a liveweight of M will kill ~0.03M^{0.475} %/km²/day

Introduction

Previous studies have shown that the numbers of tsetse attracted to a host are correlated with the liveweight of the host (Vale, 1974; Hargrove *et al.*, 1995) and the proportion that subsequently feed is correlated with host age (Torr, 1994; Torr & Mangwiro, 2000). In cattle for instance, a fully-grown ox attracts twice as many tsetse as a calf, and of those attracted ~50% feed on the ox compared to ~10% on the calf (Torr & Mangwiro, 2000). For cattle, these findings have two important practical implications. Firstly, the probability of an animal contracting trypanosomiasis increases with the frequency of tsetse bites and, secondly, when the animal is treated with insecticide, its efficacy as a bait for controlling tsetse also increases with the numbers of tsetse that attempt to feed upon it.

Most natural and domestic hosts of tsetse are generally gregarious and thus while we have some understanding of the factors affecting the numbers of tsetse feeding on an individual host, we have no idea how these factors play out when hosts are grouped together. For instance, is the number of tsetse attracted to a herd some function of the herd's liveweight? Do tsetse attracted to a herd of cattle still feed preferentially on the older and larger animals?

Other cattle management practices may also affect tsetse-cattle contact. For instance, most cattle spend various amounts of time in a kraal. Zero-grazed cattle spend all their time in a kraal and even grazed cattle are generally brought back to their kraals at night to protect them from theft and predators. In the Mudzi District of Zimbabwe and Tanga region of Tanzania, livestock owners released their cattle from the kraal at ~1-2 h after sunrise and returned them there ~1-2 h before sunset (see section 3). Consequently, cattle are generally in their kraals during the peak periods of feeding activity in tsetse. The kraals in the study areas vary from roofless structure with a surrounding fence of logs to one with a roof and a solid wall. Roofs and walls can reduce the attraction of tsetse to baits (Vale, 1999) and thus the kraaling of cattle may affect the feeding success of tsetse.

A second potentially important influence on tsetse feeding success relates to the presence of herdsmen. The presence of humans in the vicinity of cattle can reduce the numbers of tsetse feeding on cattle by 90% (Vale, 1974; 1977). Since cattle herds in Africa are generally accompanied by herdsmen, this might be expected to reduce the numbers of tsetse feeding on the cattle.

In this section, we report various studies undertaken in Zimbabwe aimed at investigating these issues.

Activities

All field studies were carried out at Rekomitjie Research Station in the Zambezi Valley of Zimbabwe where *Glossina pallidipes* Austen and *G. morsitans morsitans* Westwood occur. All experiments were undertaken between April 1998 and March 2000.

Cattle. - Mashona cattle were used in all studies. To prevent trypanosomiasis, adult cattle at Rekomitjie were treated at three-month intervals with isometamidium (1 mg/kg; Trypamidium, Rhône Mérieux). Any animals that developed trypanosomiasis were treated with diminazene aceturate (3.5 mg/kg; Berenil, Hoechst) and then treated with isometamidium 14 days later.

The Packed Cell Volume (PCV) of the herd at Rekomitjie was measured at 10-20 day intervals. Blood was collected from an ear vein into a heparinized capillary tube and the PCV of the blood was measured after spinning the sample in a haematocrit centrifuge for 5 min. The weights of cattle were recorded at 10 day intervals and condition score was measured monthly. Newly born calves were not treated with either isometamidium or diminazene aceturate until their first infection with trypanosomes was detected.

Tsetse behaviour.- Studies were made of the responses of tsetse to Mashona cattle placed either as groups or individually at the centre of an incomplete ring (8 - 16 m dia) of 6-12 electric nets (Vale, 1974b), following the method of Vale (1977). The cattle were retained in a suitably-sized crush at the centre of the ring to prevent them from touching the nets but otherwise allowing them freedom of movement. The electric nets (1.5 x 1.5 m) were mounted on corrugated trays coated with polybutene. Flies that struck the net were killed or stunned and fell onto the tray or hopper where they were retained. Tsetse were separated according to the side of the net where they were caught and classed as fed or unfed according to the presence or absence of fresh red blood visible through the abdominal wall. Flies caught on the outside or the inside of the ring were presumed to be approaching or leaving the ox respectively (Vale, 1977; Torr, 1994). Following Vale (1977), feeding efficiency was estimated as the number of fed tsetse on the inside of the ring of nets expressed as a percentage of the total catch from the inside of the ring.

Attractiveness of different types of cattle.- Studies were made of the responses of tsetse presented with the choice of feeding on different animals. Pairs of different cattle were placed in two crushes arranged 4 m apart across the prevailing wind direction. An electric net (1.5 x 1.5 m) was placed 0.5 m downwind of each crush so as to intercept tsetse as they approached the animals. To increase the numbers of tsetse attracted to the cattle, artificial odour, comprising a blend of carbon dioxide (2 l/min), acetone (500 mg/h), octenol (0.5 mg/h), 4-methylphenol (0.8 mg/h) and 3-n-propylphenol (0.1 mg/h), was dispensed midway between the two crushes.

Pairs of animals were compared for 6-8 days, with each pair of animals being swapped randomly between the two crushes to obviate any systematic bias in the numbers of tsetse attracted to a particular crush.

Experimental design and analysis.- All experiments were carried out during the 150 min preceding sunset when tsetse are most active (Hargrove & Brady, 1992). For experiments using the ring of electric nets, only one site was used. Groups of adjacent days were regarded as different blocks and treatments were allocated randomly to days within these blocks.

All experiments were analysed using GLIM4 (Francis *et al.*, 1993) which fits models using a maximum likelihood method. To analyse changes in catch, the catches (n) were transformed to $\text{Log}_{10}(n+1)$ and then subjected to analysis of variance. To analyse the proportions of tsetse feeding, a binomial model with a logit link was used and the significance of changes in deviance were assessed by χ^2 or by an F -test after re-scaling (by dividing Pearson's χ^2 by the degrees of freedom) if the data displayed a small amount of overdispersion (Crawley, 1993). Means are accompanied by their standard errors unless stated otherwise.

Outputs

Effect of herd size

Studies were made of the numbers of tsetse attracted to herds of different size. The number of tsetse attracted to a herd increased as curvilinear function of the herd. For instance, a group of four cattle attracted about twice as many *G. pallidipes* as a single animal (Fig. 1) whereas a group of 12 cattle attracted only four times as many (Table 1). This relationship is in general accord with results from previous studies where the odours from 1-60 tonnes of cattle were dispensed as a *single* odour source (Hargrove *et al.*, 1995).

Table 1. Mean number of tsetse attracted to a single ox or a group of 12. Catch index is the detransformed mean catch from a group of 12 oxen expressed as a proportion of the catch from a single ox.

Species	Sex		1 ox	12 oxen	se	Catch index
<i>G. m. morsitans</i>	Male	Mean	2.9	4.2		1.45
		Transformed mean	0.591	0.713	0.038	
	Female	Mean	4.8	8.9		1.85
		Transformed mean	0.766	0.997	0.063	
<i>G. pallidipes</i>	Male	Mean	12.8	51.1		3.99
		Transformed mean	1.140	1.717	0.043	
	Female	Mean	27	115.5		4.28
		Transformed mean	1.447	2.066	0.039	

Effect of herd composition

Studies were made of the feeding rates of tsetse attracted to a group of four cattle of different composition. The results (Fig. 1) show that when a herd was comprised entirely of young animals or adults the feeding rates were 55% and 5% respectively. However, when the herds comprised a mixture of young and old animals, the feeding rate was ~55%, and not significantly different from that observed with a herd comprised entirely of adults. The results suggest confirm previous results showing that tsetse are less successful when feeding on young cattle. In addition, however the present results show that in a mixed herd of young and old cattle, the mean feeding rate appears to be the similar to that observed with older cattle, suggesting that tsetse fed preferentially on the older animals within the group. In further studies of heterogeneous groups of eight animals, the feeding rates were 65% ($n=499$) and 27% (79) for groups of adults or young animals respectively, compared to 42% (313) when the group comprised seven young animals and a single adult. These results suggest that tsetse are still taking feeds preferentially from the adult, but that the larger proportion of young animals is reducing feeding success.

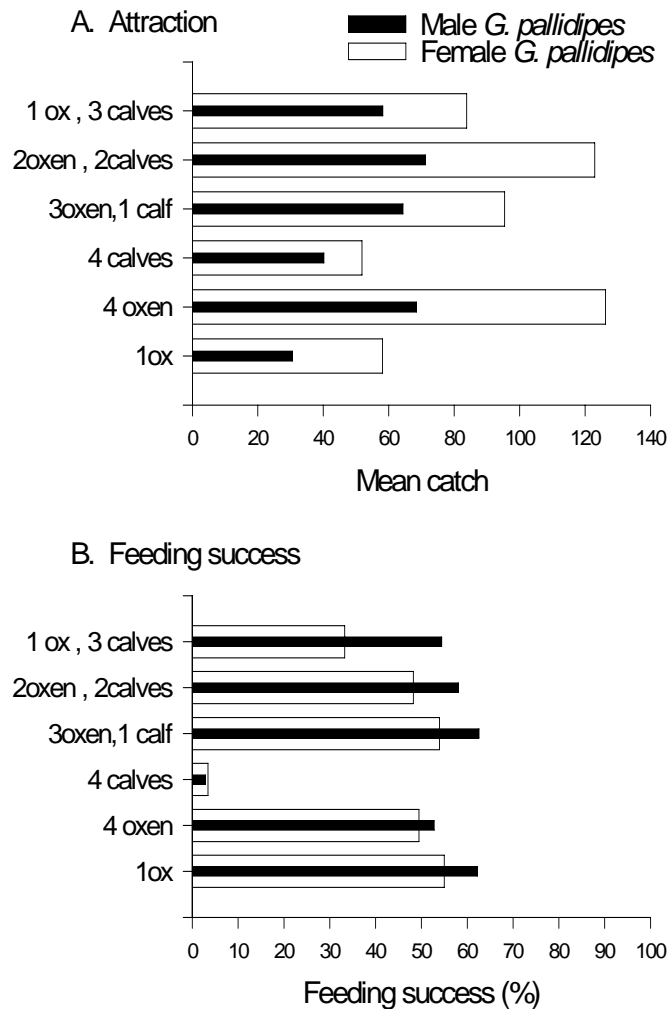


Fig. 1. Detransformed mean catch and percentage feeding success of *G. pallidipes* attracted to a single ox or groups of four cattle comprising various combinations of calves and adults.

Feeding in tsetse: choices between cattle.

Studies of the numbers of tsetse attracted to pairs of different cattle (Table 2) show that there was not a marked difference in the numbers of cattle approaching the different types of cattle. The result is rather surprising, especially given that previous work has, for instance, shown for instance that large objects are more attractive than smaller ones (Vale, 1974; 1993) and oxen are more attractive than calves (Torr & Mangwiro, 2000). In comparisons where an ox was paired with no object, then tsetse clearly chose the ox, suggesting that the protocol can detect choices. And interestingly, when the ox was paired with a man, a significantly greater number of tsetse were caught by the net downwind of the ox. These results suggest that within a herd, tsetse are equally likely to approach all the animals within the herd, but the probability of landing and feeding is influenced by the host.

Table 2. Percentage of tsetse caught on the downwind side of an electric net placed downwind of objects 1 and 2, the total downwind catch from both nets (*n*) and the probability (*P*) that the percentages are significantly different; ns indicates $P>0.05$

Experiment	Object 1	Object 2	Species	Percentage		<i>n</i>	<i>P</i>
				Object 1	Object 2		
1	Ox	Calf	<i>G. m. morsitans</i>	71.4	28.6	28	ns
			<i>G. pallidipes</i>	61.5	38.5	174	
2	Ox	Hog model	<i>G. m. morsitans</i>	45.5	54.5	22	ns
			<i>G. pallidipes</i>	63.2	36.8	114	
3	Black ox	Brown ox	<i>G. m. morsitans</i>	36.0	64.0	86	<0.01
			<i>G. pallidipes</i>	40.2	59.8	413	
4	Ox	man	<i>G. m. morsitans</i>	57.1	42.9	14	<0.001
			<i>G. pallidipes</i>	78.5	21.5	130	
5	Ox	Juvenile ox	<i>G. m. morsitans</i>	53.3	46.7	30	ns
			<i>G. pallidipes</i>	49.0	51.0	343	
6	Cream ox	Black ox	<i>G. m. morsitans</i>	58.6	41.4	29	ns
			<i>G. pallidipes</i>	47.0	53.0	302	
7	Ox	nothing	<i>G. m. morsitans</i>	84.8	15.2	33	<0.001
			<i>G. pallidipes</i>	86.1	13.9	274	

Effect of kraal architecture

The numbers of tsetse attracted to and feeding on a group of four cattle retained within different types of kraal were compared. The kraals were 7 x 3 m and comprised various combinations of fence, wall and roof. The fence comprised logs, 30 cm wide and 1.5 m high placed at 30 cm intervals; the wall comprised a solid wall of logs, 1.5 m high, and the roof was made from corrugated iron and was 2 m above the ground. Six treatments were compared:-

1. No kraal
2. Fence only
3. Wall only
4. Roof only
5. Fence + roof
6. Wall + roof.

Access to the cattle varied between completely unfettered access with the 'no kraal' treatment to the wall+roof, where the only route to the cattle was via a ~50 cm gap between the top of the wall and the roof. The results show that only where kraals had a solid wall was there a slight (~10%), but significant, reduction in the proportion of tsetse feeding on the cattle. These results (Table 3) suggest that the confinement of cattle in a kraal does not, in itself, have a major effect on tsetse-cattle contact.

Table 3. Percentage feeding success of tsetse attracted to cattle retained within different types of kraal. The various structures range from the open, fenced 'kraals', typically found in tsetse-affected areas of NE Zimbabwe (treatment E), and the walled and roofed 'bomas' used by owners of zero-grazed cattle in the Tanga Region of Tanzania (treatment F).

Treatment	Bait	Wall	Roof	Percent fed	n
A	1 ox	None	None	47.9	121
B	4 oxen	None	None	55.9	329
C	4 oxen	None	Roof	54.1	294
D	4 oxen	Continuous wall	None	39.6	192
E	4 oxen	Fence (i.e. wall with 30-cm gaps)	None	57.9	252
F	4 oxen	Continuous wall	Roof	39.9	293
G	4 oxen	Fence (i.e. wall with 30-cm gaps)	Roof	61.7	253

Effect of a herdsman

Studies were made of the effect of placing a single man adjacent to either a single ox or a group of four oxen. The results show that the presence of human reduced numbers of tsetse attracted to a single ox and reduced the proportion of tsetse that fed. However there was no significant effect with the group of four oxen (Table 4). The results indicate that the repellent effect of a single herder is not apparent when the herder is attending a large herd of cattle. Consequently, it seems unlikely that herders will have a significant effect on the efficacy of herds of insecticide-treated cattle.

Table 4. Percentage feeding success of tsetse attracted to a single ox, or a 'herd' of 4 oxen with or without the presence of a human herder.

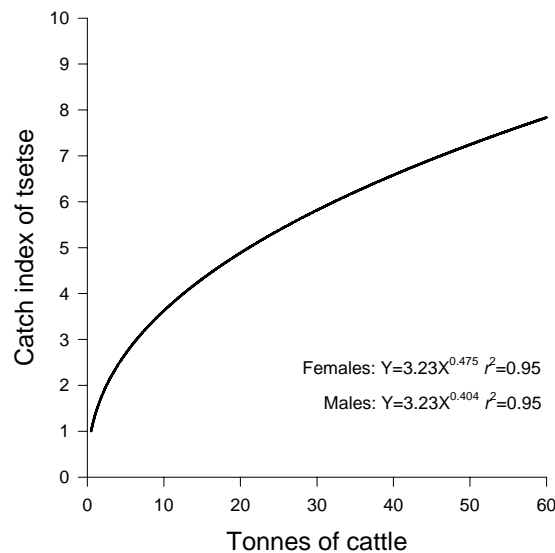
Treatment	Percent fed	N
Single ox	39.3	161
Herd	46.0	376
Ox + man	19.4	62
Herd + man	47.1	351

Implications for modelling the effects of insecticide-treated cattle on cattle populations

The present results indicate that the numbers of tsetse attracted to a herd of cattle is an exponential function of the liveweight of the herd. The results are in general agreement with those of Hargrove *et al.* (1995) where the odour from 0.5-60 tonnes of cattle were combined into a single odour source. For instance, in the present study groups of 4 - 12 oxen caught 2 - 4 times as many tsetse as a single ox which is similar to the catch indices of 2 - 3 suggested by Hargrove's data (Fig. 2).

Studies of the feeding responses of tsetse to heterogeneous herds of cattle suggest that tsetse are locating and feeding on the more tolerant animals within the herd. The data do not enable us to determine whether the tsetse locate such animals directly or via a series of failed feeding attempts on less tolerant animals. If we (conservatively) assume that tsetse locate the tolerant animals without touching the intolerant ones, and that only tsetse that fed contacted the cattle, then ~50% of tsetse attracted to a herd of insecticide-treated cattle will be killed. This efficiency is similar to that of traps and odour-baited targets (Vale, 1993).

The presence of herders and kraals had an effect on attraction and feeding success only when a single ox was accompanied by a man, or when the oxen were retained in a kraal with a roof and a wall. In Zimbabwe, cattle management practices are such that cattle are almost always in groups and not retained in kraals with roofs and solid walls. In the Tanga region of Tanzania, however, zero-grazed cattle are generally retained in walled and roofed structures and people are frequently in close proximity. Accordingly, it is to be expected that these practices will reduce tsetse-cattle contact. On the one hand this will reduce the probability of contracting trypanosomiasis, but on the other hand, it would decrease their efficiency as baits for tsetse control. Given that: odour-baited targets produce a daily mortality of 2%/km² (Vale *et al.*, 1986; Vale, 1993); a single ox attracts as many tsetse as an odour-baited target (Torr *et al.*, 1997) and; that kraaling and herding do not have a major effect on the numbers of tsetse contacting a herd, then a herd of cattle with a liveweight of M (tonnes) will kill $\sim 0.03M^{0.475}$ %/km²/day.



(Source: Hargrove *et al.*, 1995)

Fig. 2. Numbers of tsetse attracted to dose of odour derived from the data of Hargrove *et al.* (1995). Catches are expressed as a proportion of the numbers attracted to a single ox. Oxen used in the present study weighed ~ 400 kg and thus the catch indices expected for herds of 4 – 12 oxen are 2 – 3 respectively compared to the observed indices of 2 - 4.

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The development of an optimised simulation to model the effect of baits on a population of tsetse flies *Glossina pallidipes*: the Rifa Triangle experiment.

Summary

A review of the literature suggests that tsetse movement is best modelled as a diffusion process with a daily displacement which will seldom be less than 200 m or more than 1 km. The pattern of growth in tsetse populations has been less extensively studied but there is evidence that it can on occasion approximate a logistic growth process. In the absence of evidence in favour of any other model for growth it is assumed in this study that we are dealing with tsetse populations which are growing logistically. In this process the growth is approximately exponential when numbers are low, but the rate decreases as the population size approaches the carrying capacity (K). The maximum rate of growth (r) is unlikely to exceed 1.5% per day and will be much lower than this in marginal habitats.

The assumption of diffusive movement and logistic growth leads to a differential equation formulation known as the Fisher equation for which there is no known analytical solution. We can, however, approximate the changes occurring over small *finite* time steps in a grid whose mesh we can define as we wish. This is most conveniently done using a spreadsheet whose cells are taken to represent blocks of land.

This approach has been used in modelling the changes in populations of *G. pallidipes* during an experiment carried out in the Rifa Triangle, Zambezi Valley, Zimbabwe in 1984-1985. In this experiment odour-baited insecticide targets were deployed over a 600 km² area over a 16 month period. Tsetse populations were monitored using odour-baited traps, both within the treated area and in adjacent untreated country.

Preliminary simulations were carried out in EXCEL using macros written in Visual BASIC. Reasonable fits to the data were obtained but it was not clear whether these were optimal. Accordingly the simulation routine was also written in FORTRAN and linked to a non-linear least-squares optimisation routine. Improved fits have been achieved in which the rates of population growth and movement and of added mortality due to the presence of targets are all allowed to vary.

Further work is required to produce the best fits but it is already obvious that parameter estimates available in the literature provide a reasonable basis for modelling various control options.

Introduction

Over the past 30 years there has been a progressive decline in the amount of money spent by African governments on the control of tsetse and trypanosomiasis, and on associated research. Moreover, the proportion of budgets spent on operations has steadily declined in favour of spending on salaries. There have been consequent reductions in the scale of tsetse control campaigns in almost all affected countries. The tendency has been accelerated recently by a more recent decline in donor support accompanied, and partly caused, by growing concerns about the wisdom of removing tsetse from large tracts of land. In particular, there are concerns in the donor community that environmental considerations are given insufficient weight in planning the operations and that agreed land-use plans cannot be enforced.

Donors have increasingly moved towards a position where they are not willing to fund the eradication of tsetse from land which is not currently used. Thus, the East African regional programme entitled *Farming in Tsetse Controlled Areas* is funded with the clear understanding that donor money will be used to alleviate problems for people who are already farming in tsetse areas.

The overall impact of all these changes is that the entire scale of tsetse and trypanosomiasis control operations is decreasing and that there will be a shift from campaigns which achieve eradication to those which simply contain the disease problem within acceptable limits. There is, moreover, increasing pressure from donors to persuade African governments that, since livestock raising is a commercial operation, tsetse control should be the responsibility of livestock owners. In particular it has become fashionable to think that tsetse control can, and should, be carried out at the community level. It is furthermore understood that the operations can, and should ultimately be, paid for by the livestock owner.

There is every prospect that these trends in disease control, or lack of it, will continue for the foreseeable future. There appears to have been little thought, and less discussion in the literature, given to the effects of these changes in policy. In particular there has been little discussion as to precisely *how* local communities will effect disease control - particularly when such control passes to the logical end-point of full cost recovery.

It may, however, be stated with some confidence that such methods of tsetse control as large-scale ground and aerial spraying will be outside the technological and financial capacity of local communities. It therefore seems inevitable that tsetse and trypanosomiasis control will rely increasingly on a combination of the use of trypanocidal drugs and on bait methods of tsetse control. One such bait method involves the application of insecticides, specifically the synthetic pyrethroids, to livestock - either by way of dipping or as a 'pour-on'. This method has attracted considerable attention in recent years and is now widely used in Africa, but it is fair to say that our understanding of the potential of the method and, more importantly, its limitations are far from perfect (Hargrove, 1998).

The present project attempts to assess the situations in which the use of insecticide-treated cattle is a sensible strategy for tsetse control. This assessment is made primarily from an economic standpoint, but it is envisaged that the study will also identify situations where the approach will not work, regardless of the financial implications. The project involves

practical field assessment of the problem, and theoretical modelling of the observed field situations. The latter problem is the concern of the present paper. The aim is to be able to predict the outcome of particular control interventions. In the present case the particular interest is in the effect to be expected on tsetse populations from particular deployments of treated cattle, but it is envisaged that the method could be expanded to predict the effect of any tsetse control operation.

A pre-requisite for such predictions is a suitable model for tsetse population dynamics. In particular we need to know: i) The natural growth rate of the target population. ii) The effects of imposed mortality on that population. iii) The rate at which tsetse move in real control situations - since this decides the rate at which tsetse move into areas where they are being controlled.

Activities

Choosing appropriate models

The rates at which cleared areas are lost to tsetse depends on the rates, and patterns, of population increase and of population movement, or dispersal. The estimates we produce depend therefore on our choice of models for these the two components and it is therefore important that the literature on the subjects is reviewed in order to justify the models chosen.

Models of movement

The early studies of Jackson (1933 *et seq.*) led him to think that tsetse were largely restricted to ‘ambits’ – being well defined areas where the flies lived and fed. It would therefore be wrong to ‘think of tsetse as diffusing as so many molecules of gas’ (Buxton, 1955). In fact all later authors on the subject have concluded that some manner of random movement, or diffusion, process provides the best description of the observed data on tsetse dispersal.

Bursell (1970) led the attack on Jackson’s ideas when he found that catches from bait cattle gave very different pictures of fly distribution and movement than those methods previously provided by man fly-rounds. The ambit theory was seen as a complex artefact of sampling bias. Bursell claimed that the data were as well explained by a random walk model which was a far simpler model - and had the added attraction that it made no demands on the ability of the fly to navigate in extensive, apparently homogeneous, woodland.

Rogers (1976), similarly, fitted a random walk model to Jackson’s (1946) data and to his own mark-release-recapture data on *Glossina fuscipes fuscipes*. He supported Bursell’s (1970) conclusion that Jackson’s ambit theory was an unnecessarily complicated interpretation of the mark-release-recapture data. Like Bursell, he provided fits to data using a model in which tsetse made daily displacements of constant length, but random direction.

The classical data were re-analysed by Hargrove (1981), who concluded that Bursell and Rogers had failed to appreciate the problems raised by Jackson. He showed that a random movement model in which rates of movement were independent of time (*i.e.* fly age)

did *not* in fact provide a good description of Jackson data. This did not mean, however, that the random movement model needed to be abandoned. Such a model *could* fit the data if it was allowed that rates of movement, capture and mortality were all functions of age. Later studies (Hargrove, 1990 *et seq.*) have produced evidence that various age-related changes do indeed occur.

The fact that tsetse appear to move more rapidly as they get older complicates the modelling procedure. The problems can, however, be overcome simply by looking at a range of (constant) rates of movement and this procedure has been followed in the current study.

Views of random movement

Random movement can be modelled as a (discrete) random walk or as a (continuous) diffusion process. The latter approach was first developed for tsetse by Hargrove & Lange (1989) and later by Williams *et al.* (1992) who showed how the rate constants of the two processes were connected. For a random walk the population density in time and space is defined by:

$$\rho(r,t) = \frac{1}{\pi\lambda^2 t} \exp[-r^2 / \lambda^2 t]$$

where $\rho(r,t)$ is the probability density of finding a fly at distance r from its origin t after it started moving; $\lambda^2/2$ is the movement in the mean square displacement per unit time in the x or y direction and λ^2 is the mean square displacement per unit time in any direction from the origin.

The appropriate diffusion process is defined by the differential equation:

$$\frac{\partial \rho(r,t)}{\partial t} = \alpha^2 \nabla^2 \rho(r,t)$$

Williams *et al.* (1992) show that the two descriptions of random movement are equivalent when $\alpha = \lambda^2/4$. (That is to say, 4α is the mean square displacement per unit time in any direction from the origin). In that case:

$$\rho(r,t) = \frac{1}{4\pi\alpha t} \exp[-r^2 / 4\alpha t]$$

Hargrove & Lange (1989) pose the diffusion equation as:

$$\frac{\partial \rho(r,t)}{\partial t} = \frac{\sigma^2(t)}{2} \nabla^2 \rho(r,t)$$

which has solution:

$$\rho(r,t) = \frac{1}{2\pi \int_0^t \sigma^2(s) ds} \exp(-r^2 / 2 \int_0^t \sigma^2(s) ds)$$

and in the case when $\sigma^2 = k$, where k is a constant,

$$\rho(r,t) = \frac{1}{2\pi kt} \exp(-r^2 / 2kt)$$

so that the two descriptions of the diffusion process are equivalent when $k = 2\alpha = \lambda^2/2$. In other words k is the mean square displacement per unit time in the x or y direction and $2k$ is the mean square displacement per unit time in any direction from the origin. (This agrees with the limit as $d \Rightarrow \infty$ in Equation 6 of Hargrove & Lange's (1989) development).

In the present paper we use the unit α of the diffusion equation setting given by Williams *et al.* (1992). It is then convenient to state some of the results given by Hargrove & Lange's (1989) in terms of α instead of k . For instance, for flies released at random in a square (L) of side $2l$, the probability that a given fly is still inside the square at time t later is:

$$P_L(t) \approx 1 - \sqrt{4\alpha t / \pi l^2}$$

Suppose that $\alpha = 0.01 \text{ km}^2/\text{day}$ (so that the mean square displacement (λ^2) per day is 4α , or 0.04 km^2 and λ takes the values 0.2 km or $200 \text{ m day}^{-1/2}$). Further suppose that $l = 1 \text{ km}$. Then the probability that a fly is still in L after one day is $\approx 1 - \sqrt{4 \times 0.01 / \pi(1)^2} \approx 0.89$. The approximation relies on the fact that l is large relative to the rate of diffusion. The exact equation is given by Hargrove & Lange (1989).

Model for population growth

The pattern of *growth* in tsetse populations has not been studied as extensively as patterns of movement. It is clear, on general grounds, that populations must be regulated by some manner of density dependent mechanism (Rogers, 1979, 1990) but it is less clear at what stage such a process operates.

Following a control programme in the Lambwe Valley of Kenya, Turner & Brightwell (1986) found that the surviving *G. pallidipes* population exhibited growth which was closely similar to a logistic growth process. In the absence of evidence in favour of any other model for growth we follow these authors, and Williams *et al.* (1992), in assuming that we are dealing with tsetse populations which are growing logistically with growth rate r and carrying capacity K . The rate of change in the population density ($\rho(t)$) at time t is then given by:

$$d\rho(t)/dt = r\rho(t)[1 - \rho(t)/K]$$

If an additional mortality rate (δ) is imposed on the population, by for instance the deployment of insecticide treated targets or cattle, then the above equation must be modified to read:

$$d\rho(t)/dt = r\rho(t)[1 - \rho(t)/K] - \delta\rho(t)$$

Williams *et al.* (1992) point out that if we take

$$r^* = r(1 - \delta/r) \text{ and } K^* = K(1 - \delta/r)$$

then we can rewrite this equation in the form

$$d\rho(t)/dt = r^* \rho(t)[1 - \rho(t)/K^*]$$

Combining the differential equations for movement and for growth then gives:

$$\frac{\partial \rho(r^*, t)}{\partial t} = \alpha \nabla^2 \rho(r^*, t) + r^* \rho(r^*, t)[1 - \rho(r^*, t)/K^*]$$

which is known as the Fisher equation (Murray, 1989). The equation defines the *instantaneous* changes in population density at any point, in time and space, for a population with predefined carrying capacities and rates of growth and movement.

(Notice that the only density dependent processes considered in this model act *via* the birth and death processes. We have not allowed for any density dependence in the diffusion rate; this factor *could* exist but there appears to be no evidence for its action, much less any estimate of its quantitative importance).

There is no known analytical solution to the Fisher equation. We can, however, approximate the changes occurring over small *finite* time steps in a grid whose mesh we can define as we wish. This is most conveniently done using a spreadsheet whose cells are taken to represent blocks of land.

Using a spread sheet to simulate growth and diffusion processes in tsetse populations

Suppose we define a block X of country by an $n \times n$ lattice where each cell $X(i,j)$ ($i = 1, n; j = 1, n$) is equivalent to a (1 x 1) km square. For any square $X(i,j)$ located in the interior of the block suppose the population at time t is $N_t(i,j)$. One unit of time later this population (and indeed the population in each cell of X) will have grown, due to the birth and death processes only, according to the logistic equation such that:

$$N_{t+1}(i,j) = N_t(i,j).r.(1 - (N_t(i,j)/K))$$

There will also have movement into and out of the cell – defined in the instantaneous case by the operator ∇ . In the finite approximation the change in $X(i,j)$, due now to movement only, is defined by:

$$N_{t+1}(i,j) = N_t(i,j) + (\alpha((N_t(i,j-1) + N_t(i-1,j) + N_t(i,j+1) + N_t(i+1,j)) - 4.N_t(i,j)))$$

The total change is obtained by simply adding the components in the two previous equations.

Practical aspects of the simulation

Preliminary simulations were carried out in EXCEL using macros written in Visual BASIC. EXCEL provides a spreadsheet consisting of a lattice of square cells; the unit length of the side of each square is defined equivalent to some arbitrary length on the ground. For brevity and convenience we refer below to the chosen length as the grid.

The choice of the grid size depends in the first place on the total area over which the simulation is being carried out. Thereafter the choice depends on a balance between the conflicting requirements of speed and definition. For each time step EXCEL must carry out the required calculations on each individual cell; thus the finer the grid the greater will be the detail, but also the longer will be the time required to complete the calculation.

If, for example, the total area to be studied is 100 km² one could choose a 10 x 10 lattice, with a grid of 1 km, and each time step would require 100 calculations. Alternatively one could choose a 5 x 5 lattice, with a grid of 2 km – in which case only 25 calculations per time step would be required. The former choice, given the speed of modern computers, would not present a time problem and would be a better choice than the second given that it would provide better definition.

If, however, one were studying a 10,000 km² block a grid of 1 km would imply 10,000 calculations per step and the simulation might take a considerable time. One could, alternatively, use a grid of 10 km – in which case the lattice is once again 10 x 10. To make the two simulations equivalent one must, of course, vary the value of the diffusion coefficient (α) to suit the chosen scale. This process is best illustrated by an example.

Suppose we decide to simulate a population in which the movement is characterised by a daily root mean square displacement (λ) of 0.2 km (= 200 m) per day. Since $\lambda^2 = 4\alpha$ (Williams *et al.*, 1992; see above) the appropriate value for α , with a grid of 1 km, is $\alpha_1 = (0.2 * 0.2)/4 = 0.01$ km²/day. (The subscript on α refers to the length of the side in km).

If the grid is x km, but λ is the same as for a 1 km grid, then:

$$\lambda^2 = 4 \alpha_x (\text{km} * x)^2 / \text{day} = 4 \alpha_1 / x^2 (\text{km})^2 / \text{day}$$

Thus, in general, when we change the grid (but keep λ constant) we simply divide α_1 by the square of the new grid, measured in km. Suppose, for example, we wish to change to squares of side 10 km and that, as before, $\lambda = 200$ m. Then:

$$\alpha_{10} = 0.01/100 (\text{km} \times 10)^2 / \text{day}$$

and $\lambda^2 = 4\alpha$

$$= 0.04/100 (\text{km} \times 10)^2$$

$$\lambda = 0.2/10 (\text{km} \times 10) = 200 \text{ m day}^{-1/2}$$

as before.

The required values for α for different grids are shown in Table 1. The colour coding used in the body of the table highlights situations with identical values of α - in which, by

definition, the pattern of re-invasion will be identical. Thus a simulation of the rate of re-invasion into an $n \times n$ lattice with grid 1 km and with $\lambda = 200$ m will give identical results to a simulation in which the grid is 2 km and $\lambda = 400$ m. More generally, if we have two squares of sides s_1 and s_2 and fly movements in the two areas are characterised by rates λ_1 and λ_2 then the pattern of re-invasion will be identical if $s_2/s_1 = \lambda_2/\lambda_1$.

Thus in studying the effect of changing the diffusion coefficient on rates of re-invasion into a block of a given size one is automatically looking at the effect of keeping the rate of movement constant and changing the block size.

λ (km r.m.s.d. in one day)	$\alpha_1 = \lambda^2/4$ km ² /day	$\alpha_2 = \alpha_1/4$ (kmx2) ² /day	$\alpha_4 = \alpha_1/16$ (kmx4) ² /day	$\alpha_8 = \alpha_1/64$ (kmx8) ² /day	$\alpha_{16} = \alpha_1/256$ (kmx10) ² /day
0.1	0.0025	0.000625	0.000156	0.000039	0.000010
0.2	0.0100	0.002500	0.000625	0.000156	0.000039
0.3	0.0225	0.005625	0.001406	0.000352	0.000088
0.4	0.0400	0.010000	0.002500	0.000625	0.000156
0.5	0.0625	0.015625	0.003906	0.000977	0.000244
0.6	0.0900	0.022500	0.005625	0.001406	0.000352
0.7	0.1225	0.030625	0.007656	0.001914	0.000479
0.8	0.1600	0.040000	0.010000	0.002500	0.000625
0.9	0.2025	0.050625	0.012656	0.003164	0.000791
1.0	0.2500	0.062500	0.015625	0.003906	0.000977
1.6	0.6400	0.160000	0.040000	0.010000	0.002500

Table 1. The relationship between the root mean square displacement (λ) in one day - measured in km - and the appropriate value for α in squares of different sizes. Note that cells highlighted with the same colour have the same value of α .

Choice of time step

Different problems arise when the squares are small in relation to the rate of movement. We would also like to be able to study the movement into a small block - say of side 2 km, approximately the size of the small-scale aerial spraying block used by Vale *et al.* (1983). In order to look at the detail of movements inside the square suppose we break this block into units of side 0.2 km. The value for $\alpha_{0.2}$ would then be $\alpha_1/(0.2)^2 = 25\alpha$. This would give rise to problems, however, because $\alpha_{0.2}$ would no longer be small in relation to the length of the side. The problem can be solved by taking a smaller time step in the simulation process; thus if we take a time step of 1 h (rather than 24 h) the rate of diffusion *per step* is reduced by a factor of 24 and is moved back to a value close to the daily value for a 1 km square. (The growth rate must be similarly reduced).

The Rifa Triangle experiment

In 1984-85 an experiment was carried out in Zimbabwe in which insecticide-treated, odour-baited targets were deployed in a 600 km² block of land in the Zambezi Valley known as the Rifa Triangle (Vale *et al.*, 1988). Changes in the populations of the tsetse flies *Glossina morsitans morsitans* Westwood and *G. pallidipes* Austen over a two year period were estimated from changes in trap catches of the flies at various sites inside and outside the control area. The resulting data provide a good platform for estimating the parameter values

which should be used in modelling the effect of the use of insecticide-treated cattle as agents of tsetse control.

As a preliminary step the data were modelled using an EXCEL (Visual Basic) programme. The Rifa Triangle, and adjacent areas were ‘mapped’ as a series of blocks in the spreadsheet, where each block was equivalent to a 1 km x 1 km square of country (Fig. 1). Each square was assigned values pertaining to the dynamics of the tsetse population in that area. In particular the following were stipulated: i) The natural growth rate (r). ii) The rate of movement (α). iii) The carrying capacity (K). iv) The imposed mortality (δ). In the case of δ this parameter changed both in time and space since the number of targets deployed varied during the experiment. The values of all of the parameters were varied in an effort to get a good fit to the observed data.

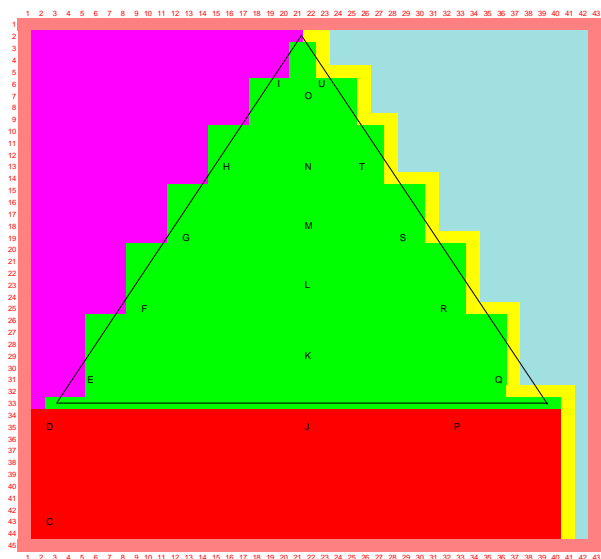


Figure 1. The EXCEL spreadsheet ‘map’ of the Rifa Triangle and adjacent areas.

Key to different coloured areas: Red - Mana Pools; Green - Rifa Triangle; Magenta - Zambezi Valley escarpment; Pale Blue - Zambia; Yellow - Zambezi River.

Scale is in km. Letters in the body of the map indicate trap sites. The traps operated at Rekomitjie Research Station are not shown (sites A and B); they lay at a distance of about 30 km from the bottom edge of the Rifa Triangle as drawn here. The traps were lumped into different areas. Area 1 - sites A,B. Area 2 - site C. Area 3 - sites D, J, P. Area 4 - sites E, K, Q. Area 5 - sites F, L, R. Area 6 - sites G, M, S. Area 6 - sites H, N, T. Area 7 - sites I, O, U.

Reasonable fits to the data were achieved varying only the flies’ rate of movement and the rate at which adults are killed by odour-baited targets. (The predicted changes in time and space of the *G. pallidipes* population are shown in Fig. 2). It was not, however, clear whether the fit was in any way optimal. Accordingly the simulation routine has also been written in FORTRAN and linked to a non-linear least-squares optimisation routine. In this way it should be possible to arrive at an optimal, parsimonious model for the population changes and, thereby, realistic estimates of rates of growth and movement. This process is

described in detail by Hargrove & Williams (1998) but is outlined here for reference purposes.

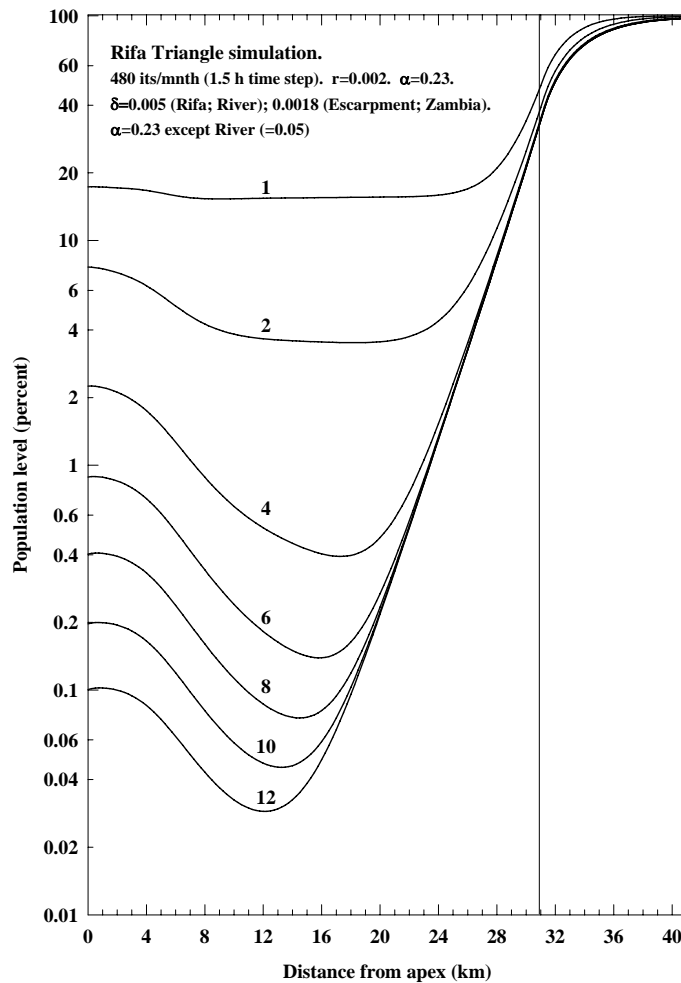


Figure 2. Simulation of changes in the population of *G. pallidipes* during the Rifa Triangle experiment. The parameter values use in the simulation are shown in the legend in the body of the map. The numbers attached to each line indicate the number of months elapsed after the start of the experiment. The 'apex' referred to is the point at which the Zambezi River enters the Zambezi Escarpment. The population values are estimated on a line drawn vertically down from this point on the map in Fig. 1.

The simulation process described above was linked to an iterative minimisation routine called SEARCH ((c) Copyright Kenneth Lange, 1985-1991) which is a FORTRAN 77 subprogram for function minimisation. In order to carry out the minimisation the following are required: i) A set of observed data. ii) A parametric model to describe the data. iii) A loss function which measures the difference between the observed and predicted data. iv) Starting values for each parameter in the model.

The minimisation starts by producing a set of predicted data with the initial parameter values as inputs. In the present case these predictions are produced using simulation. In the particular case of the Rifa Triangle data the simulation procedure produces predicted population levels in each (1 km x 1 km) square of the study area. The simulation used had

time steps of a fraction of 0.25 of day but, since the observed data consisted only of bi-monthly mean trap catches, it was only necessary to store the predicted population levels every 250 time steps, and then only in the squares corresponding to the trap sites.

The difference between the observed and predicted data was used to calculate a value for an appropriate loss function. Each parameter for the model was then, in turn, perturbed slightly (positively then negatively, with all other parameters kept at their initial values) and the predicted data and loss functions recalculated via simulation. This allowed the programme to identify the change in the loss function, and its first and second derivatives, with respect to each parameter. The information was used to select a new set of parameter values which, when used again to recalculate the predicted data, results in a reduction in the loss function. This procedure was iterated automatically until no perturbation could be found which resulted in a decrease in the loss function. Optimised simulation can, of course, only be used to improve models by comparing the best fits achieved with different formulations of that model; the onus is on the modeller to select candidate variables which might be of use in this regard.

Estimates of rates of movement and of population growth

The intention of the current paper is to estimate the effects the rates of dispersal and population growth pertaining in a natural tsetse population which has been subjected to a control programme involving the use of baits. It is useful, in addition, to have an idea of the published estimates of these parameters.

The literature on dispersal has been reviewed by Rogers (1977) (see also Glasgow (1963) and Williams *et al.* (1992)) and provides several estimates of the rates of advance of tsetse fronts and of rates of movement in experimental situations. These, and other, estimates are summarised in Table 2. Rogers (1977) estimated daily displacements both from short-term experimental estimates and from longer-term observations of the rate of advance of tsetse fronts. The latter estimates are less reliable, however, since the rate of advance of a front, or rates of re-invasion in general, depend not only on the rate of movement of the flies but also on the population growth rate.

Rather higher estimates of diffusion rates were obtained by Vale *et al.* (1984) in a study where tsetse were killed in a small block of woodland (*c.* 2 km x 2 km) using aerial spraying and the rate of re-invasion was monitored thereafter. The great surprise was that, for *G. pallidipes*, there was no discernible drop in trap catches even one day after the spraying. There was no question that the spray was effective in killing the flies present, since recaptures of marked flies released in the block immediately prior to the spraying indicated that at least 98% of these flies were killed.

Table 2. *Estimates of the rates of dispersal of tsetse.*

A. Rates of advance of invasion fronts

Species	Distance moved (km)	Time (years)	Rate km/year	Author(s)
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<i>G. m. morsitans</i>	3-5	1	3-5	Jackson (1933)
	59	17	3.5	Jackson (1950)
	10-11	1	10-11	Ford (1971)
	72	17	4.2	Jack (1914)
<i>G. m. morsitans</i> & <i>G. pallidipes</i>	11	1	11	Ford (1960)
<i>G. m. submorsitans</i>	3.2	0.16	20	Davies & Blasdale (1960)

B. Experimental estimates of daily displacement rates.

Species	Displacement (km)	Time (days)	Daily displacement (m)	Author(s)
<i>G. m. morsitans</i>	0.64	7	243	Jackson (1948a)
	1.6	42	249	Jackson (1948a)
	-	-	134	Jackson (1946)
	524-886	7-21	232	Jackson (1948b)
<i>G. pallidipes</i>	-	-	700	Vale et al. (1984)
	-	-	800	Vale et al. (1984)
<i>G. swynnertoni</i>	-	-	246	Jackson (1948b)
<i>G. longipennis</i>	-	1	397	Power (1964)

A preliminary analysis suggested that the results could only be explained if this species, under the particular conditions of the experiment, had a daily displacement of the order of 1 km. It could be that it over-estimates the true value for λ since the traps were attracting and intercepting flies during their day's flight and is closer to the extreme of the day's displacement rather than to its mean. In the absence of further evidence the figure of 1 km is taken as an upper bound for present purposes but it is acknowledged that daily displacements may seldom approach this limit.

Outputs

In performing the modelling the study area was split into various zones:

1. The Mana Pools area (coloured red) where no tsetse control was carried out. The carrying capacity (K) was set at an arbitrary level of 100, the growth rate (r) was initially set at a fixed level of 0.01 per day, but in later runs was entered as a parameter. There was no imposed mortality (δ) in the Mana area. The diffusion rate (α) was initially assumed to be the same in all areas and was always entered as a parameter.
2. The Rifa Triangle (coloured green) where target density was progressively increased between March and September 1984. The natural values of K and r were assumed to be the same as for the Mana area but, in each square of the Triangle, an additional mortality (δ) was imposed. The mortality was assumed to be directly proportional to the number of targets deployed in that square.
3. The Zambezi escarpment (coloured magenta) where no targets were deployed but which was ground-sprayed with DDT in September 1984. Prior to the spraying the area was assumed to have the same characteristics as the Mana Pools area. Thereafter it was assumed that it had a negative growth rate of -0.2 per day and, accordingly, a negative carrying capacity.
4. Zambia (coloured pale blue) where there has been extensive destruction of habitat and of game and where the area is settled the tsetse populations are known to be lower than on the Zimbabwe side of the river. As an initial estimate it was assumed that the carrying capacity was only 1% of that in the Mana Pools area and that the growth rate was only 0.005 per day.
5. The Zambezi River (coloured yellow). For the southern half of the river the values of K, r and δ were assumed to be the same as for the Rifa Triangle; for the northern half they were assumed to be the same as for Zambia. As mentioned above the diffusion rate (α) was initially assumed to be the same as in other areas; in later runs it may be more realistic to assume that the river acts as a partial barrier so that the rate of diffusion across it would be reduced.

It was not possible, during the Rifa Triangle experiment, to sample all monitoring sites simultaneously. Mean daily trap catches of *G. pallidipes* at various sites (Fig. 3) were accordingly estimated from catches pooled over two month periods. Catches made near Rekomitjie Research Station, situated about 30 km from the edge of the Rifa Triangle, were regarded as the controls. Catches at other sites were estimated as the percentages of the Rekomitjie levels. As expected, however, the catches even in the control area at Rekomitjie varied with time. It was assumed that the variation in the Rekomitjie area was about a mean of 100% (Fig. 3a). Note that in plotting the data each estimate was transformed by taking $\log_{10}(\text{percentage} \times 10,000)$. An estimate of 100% thus gives a transformed value of 6.0. The constant multiplicative factor of 10,000 was introduced to avoid negative transformed values

of means from other sites where the percentage catch was very low once the control operation was under way. It was also necessary to add a small constant percentage (0.00001% was chosen) to each estimate (observed and predicted) in order to prevent taking the log of zero values.

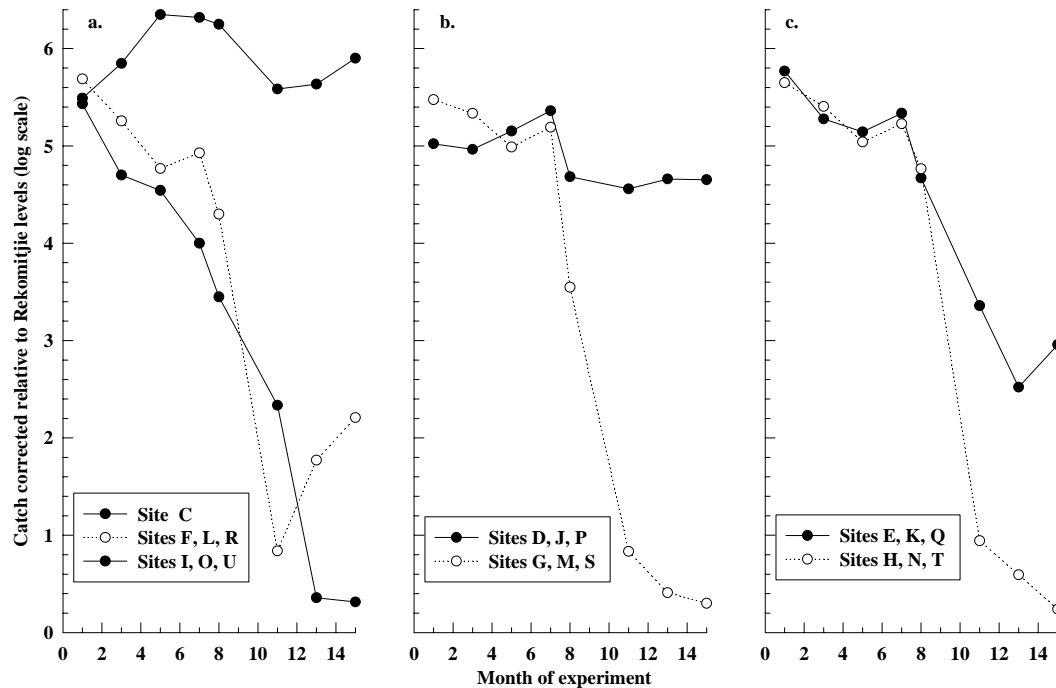


Figure 3. Mean trap catches of *G. pallidipes* from various areas in and around Rifa Triangle, Zambezi Valley, Zimbabwe, 1984-1985. Means calculated as described in the text for samples from all sites indicated over two month periods.

Model where only the killing rate (δ) per target was allowed to vary

In this model values of r and α were fixed at what appeared to be reasonable levels ($r = 0.01/\text{day}$ and $\alpha = 0.01 \text{ km}^2/\text{day}$) and only the killing rate (δ) per target was allowed to vary. The residual sums of squares (RSS) for the best fit was 56.5 and the corresponding value of δ was 0.00226 with a standard error of 0.00123.

Model where the killing rate (δ) per target and diffusion rate (α) were both allowed to vary

The growth rate was again fixed at 0.01/day. The algorithm did converge with values of α and δ of 0.00245 and 0.00225 respectively. However, the RSS was no lower than in the model where only δ was allowed to vary. Moreover the standard error for the value of α , at 0.0106 was markedly higher than the mean. This suggests that variation in the rate of movement is not an important factor in explaining the variation in trap catches. This seems inherently unreasonable and may mean that there are problems with the way in which the simulation procedure is being carried out.

Model where the grow rate (r) was also allowed to vary

In preliminary runs with this model it was possible to get significantly better fits with the one and two parameter models but the results are so far unsatisfactory in that the optimal values of r are unrealistically low and have so far always hit the lower boundary. It has not been possible so far, therefore, to produce an optimal fit with standard errors assigned to each parameter.

Possible problems with the fitting procedure

One obvious problem with the procedure relates to the weighting of the data. The mean trap catches varied, between sites and over time, by six orders of magnitude and it is not at all clear how one should weight the various observed estimates. Clearly some transformation must be carried out - otherwise the sums of squares will be entirely dominated by the high trap catches and will take no notice of small differences in trap catches, for instance, of the order of 1%.

It was to take care of this problem that all catches were transformed to logs. This procedure may, however, have given undue weight to small differences at the bottom end of the catch scale. It is for this reason that the fits to the data in areas 2 and 3 (Fig. 4) are particularly poor. These areas are outside the Rifa Triangle and were not as seriously affected by the targets as the areas inside the target treated area. The algorithm is therefore 'ignoring' the relatively minor changes in trap catches there. It is probably for this reason that the results so far indicate little effect of the rate of movement on the goodness of fit. Further work is being carried out in an effort to solve these problems.

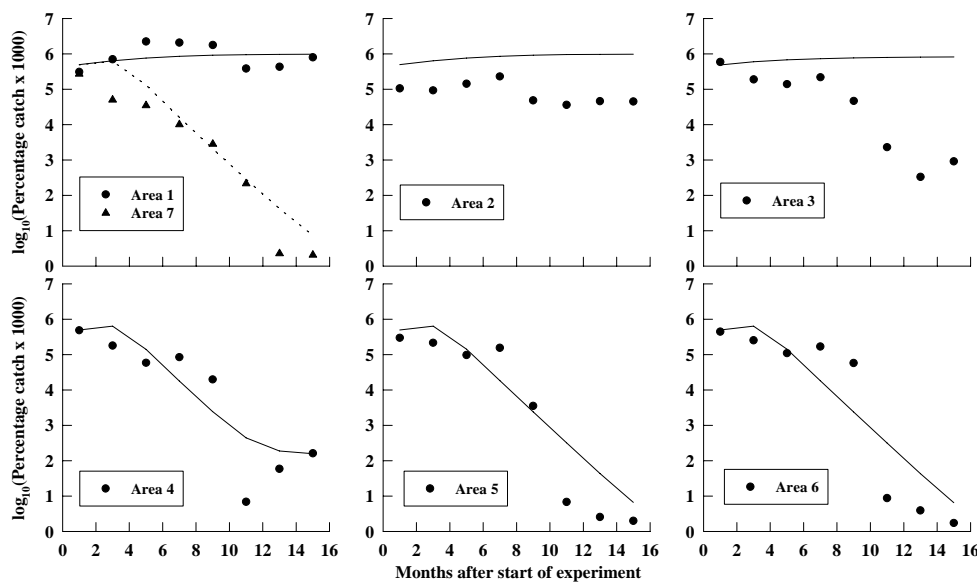


Figure 4. Changes in populations of *G. pallidipes* as estimated from trap catches in different areas in and around the Rifa Triangle, Zambezi Valley, Zimbabwe. Example of a fit achieved using optimised simulation.

What the work does indicate already, however, is that in real control situations the parameters for rates of natural growth and movement and the killing rates attributable to targets (or treated cattle) are unlikely to be far from the values generally quoted in the introduction to

this paper. Thus, even if the optimised simulation procedure fails to deliver the best possible fit to the data we may be reasonably confident in proceeding to model various control options using these existing parameter estimates.

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Insecticide-treated cattle for tsetse control in Zimbabwe: cattle management practices in north-east Zimbabwe.

SUMMARY

In 1997, tsetse from infested areas of Mozambique invaded tsetse-free areas in the Mudzi District of Zimbabwe by penetrating a barrier of insecticide-treated cattle (ITC) deployed along the border. The Government of Zimbabwe rapidly rectified the situation by deploying insecticide-treated targets along the border. The present study aimed to determine why the cattle- and target-barriers had such different effects.

The distribution and abundance of people and cattle in the Chikwizo area were mapped using a combination of: participatory mapping techniques, aerial photography, ground-based cattle surveys and continuous herd tracking with geographical positioning systems. These direct methods were complemented by analysis of Government of Zimbabwe records of cattle numbers.

The studies showed that cattle were unevenly distributed, with ~75% of cattle being confined to a 50km² central block on the western edge of the barrier. Consequently, virtually cattle-free corridors, 4 km wide, existed along the border and along two drainage systems running across it. Simulations were performed of tsetse control operations involving the use of insecticide-treated cattle and/or odour-baited targets. The results were in accord with the observations that the existing barrier of odour-baited targets prevented any substantial re-invasion of tsetse from Mozambique whereas the barrier of insecticide-treated cattle was ineffective. The target barrier was more effective because targets were deployed in the cattle-free corridors. It is concluded that properly managed and appropriately applied, insecticide-treated cattle and odour-baited targets are powerful weapons in the arsenal of tsetse control weapons. But, as with all such weapons, their indiscriminate use, without due regard to potential levels of re-invasion and without an interactive approach, will often be disastrous both from a veterinary and from an economic point of view.

Introduction

In Zimbabwe, tsetse have been eradicated from most areas apart from infestations in the north-east of the country, bordering Mozambique and Zambia. Consequently, most tsetse control operations in Zimbabwe are now directed at maintaining barriers to prevent tsetse re-invading from neighbouring countries (Shereni, 1990). These barriers consist of odour-baited targets, treated with insecticide, and, where possible, the treatment of all cattle adjacent to the barrier with the synthetic pyrethroid deltamethrin, either as a dipwash at two-weekly intervals, or as a pour-on at monthly intervals.

In the Mudzi District of NE Zimbabwe, Warnes *et al.* (1999) studied the efficacy of using just insecticide-treated cattle as a barrier to tsetse. Their results demonstrated that tsetse readily penetrated through such a barrier resulting in an increased incidence of trypanosomiasis in local herds. They concluded that under the conditions of the field trial, the insecticidal treatment of local cattle did not in itself form an effective barrier to tsetse re-invasion. The present study aimed to determine what particular conditions contributed to the failure.

Activities

Cattle ownership, distribution and management practices

The study mainly focussed on cattle owners in Chikwizo A ward (Fig. 1), an area of ~250 km² which includes the area where tsetse penetrated the cattle barrier (Warnes *et al.*, 1999). Chikwizo A comprises 23 Kraals which are divided into six villages (Kasoro, Chando, Mupaso 1, Kanyoka, Nyamukacha and Nyamhasa). Local administrative structures are both traditional (chiefs, or kraalheads) and more recently introduced elected village and ward development committees (VIDCOs and WADCOs).

Cattle numbers and herd compositions.- The numbers of cattle within the ward was estimated from a number of sources. First, cattle census data were obtained from the Zimbabwe Department of Veterinary Services; these data provide monthly records of the numbers of cattle registered at each animal inspection centre. Second, the numbers of cattle and their owners attending government-funded dipping were recorded, together with household and kraal names. Almost all the cattle kraaled and/or grazed within the trial boundary are registered at one particular dip, Zano. The dips are free at the point of delivery and thus, in the wet season at least when cattle are at greatest risk from tick-borne diseases, >80% owners attend (Warnes *et al.*, 1999). Third, groups meetings were arranged with the kraalheads and livestock owners from the six villages lying within Chikwizo A. At the meetings, livestock owners provided dip cards which detail the number and composition of cattle owned and the kraalheads provided details of the number of cattle owners in the village, some of whom were not at the meetings.

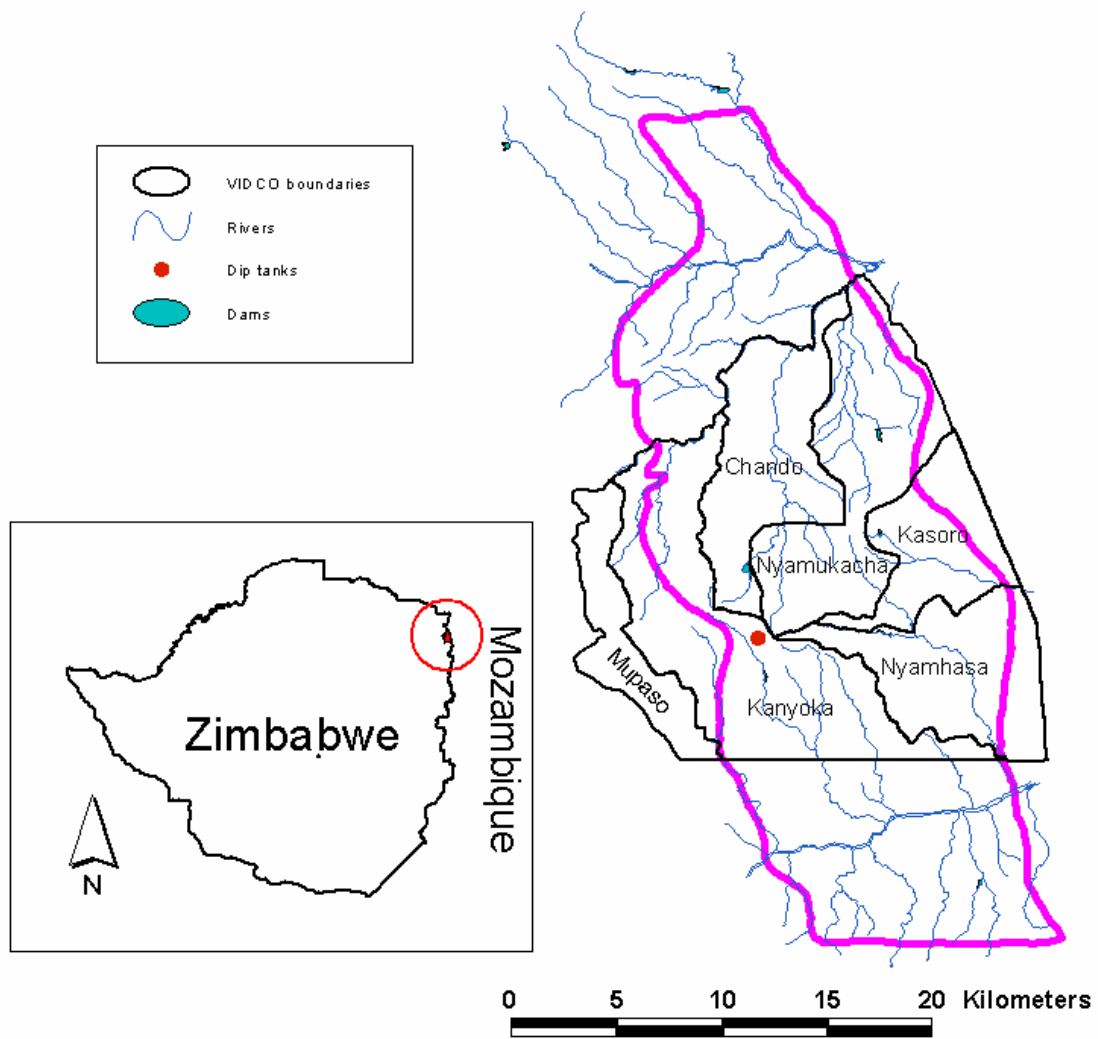


Fig. 1. Mudzi trial area showing the extent of the tsetse barrier (solid purple line), and the six VIDCOs comprising Chikwizo A ward which were the focus of this study. The inset shows the location of Chikwizo ward in relation to the rest of Zimbabwe (red area at the centre of the red circle).

Cattle distribution.- At the farmer group meetings, participatory mapping techniques were used to estimate the grazing patterns of cattle through the year. At each meeting a map of the area was drawn together with the cattle owners. Main identifying features were marked (such as roads, rivers, tracks, hills, dams etc.) and then each cattle owner marked the position of his/her homestead. The group were then asked to indicate their grazing areas and watering points, seasonal differences in use and the minimum and maximum distances travelled. Farmers were also asked to identify areas on the map where their cattle come into contact with wild hosts and the areas they perceive to be worse in terms of tsetse fly numbers.

Following these meetings, surveys were conducted to determine whether herds were indeed grazing in the areas indicated by the owners. During these surveys, 2 - 4 field assistants visited the different grazing areas and the positions of any herds that they found were recorded using a geographical positioning system (GPS; Garmin XL, Garmin, Romsey, UK). In addition, the size and composition of the located herds were noted, the owner(s) name was recorded and the herders were asked about their kraaling practices, grazing areas and waterpoints used. These surveys were conducted in February, July and October 1999 during the: (i) wet season, (ii) cold season, after crops have been harvested, and (iii) the hot season. In the hot season, grazing herds are not accompanied by herders. Consequently, the grazing ranges of 10 different herds were mapped by field assistants who followed a herd for a day. The field assistant carried a GPS which was programmed to record their position at 2-minute intervals.

Location of kraals.- During the surveys and village meetings, the locations of individual kraals were recorded using a GPS. In addition, aerial photographs of the area, taken by a Government of Zimbabwe aerial survey conducted in 1997, were used to produce a vegetation map of the area. The ward was divided into a grid of 1-km² cells and each cell was scored according to the percentage of area covered by: 1. open grassland, 2. open woodland, 3. medium woodland, 4. dense woodland, 5. farmland and 6. water.

Village and administrative boundaries.- Village, ward and national boundaries were obtained from Government of Zimbabwe maps of the area. In addition, villagers indicated their local understanding of village boundaries with reference to various features such as trees, boulders and road junctions. These *de facto* boundaries were also recorded using a GPS.

Analysis of spatial data

The various spatial data, (e.g. positions of herds, kraals, villages, vegetation types) were incorporated into Geographical Information System (GIS) using the software package Arcview (ESRI, Aylesbury, UK) for analysis. The study area was divided into a grid of 1 km² cells and the probabilities of finding a herd in any given cell.

Changes in tsetse populations were modelled using the Fisher equation which defines the *instantaneous* changes in population density $\rho(\mathbf{x},t)$ at any point \mathbf{x} and at any time $t \geq 0$, for a population with predefined carrying capacity K and rates of growth r and movement α (Williams *et al.*, 1992; Hargrove, 1998; Hargrove, 1999). If an additional mortality rate (δ) is imposed on the population then the growth rate and carrying capacity become $r^* = r(1 - \delta/r)$ and $K^* = K(1 - \delta/r)$ respectively; the Fisher equation applies as before with r^* substituted for r and K^* substituted for K .

The model assumes that tsetse populations move by diffusion and grow logistically. The population changes occurring over small *finite* time steps are modelled using Excel spreadsheets with programmes written in Visual basic. The procedure is described fully by Hargrove (1998, 1999). In most cases pre-control tsetse population levels were assumed to have an arbitrary carrying capacity of 100 units in each cell. Distributions of insecticide-treated cattle and/or odour-baited targets were used to estimate the value of δ in each case.

Cost-effectiveness, acceptability and sustainability of insecticide-treated cattle

At the group meetings, cost-effectiveness, acceptability and sustainability of insecticide-treated cattle as a tsetse control method were explored both directly and indirectly with the livestock owners. The role of cattle in the farming system and farmers’ perceptions of constraints (particularly diseases) were discussed. Farmer understanding, and perceptions of the severity, of tsetse and trypanosomiasis were explored, as were views concerning different control options.

Outputs

Cost-effectiveness, acceptability and sustainability of insecticide-treated cattle

Role of cattle in the farming system and cattle constraints.- In order to understand the importance of cattle in Chikwizo A, the groups were asked to list and rank the reasons why they kept cattle. The results from the different groups were very similar. The most important reason for keeping cattle in all the villages is for draught power. The other reasons, in order of importance, were: sale of live animals, manure, milk, meat and hides. Cattle are generally sold to cover specific large expenses, particularly in order to pay school fees.

The groups were asked to list (but not rank) their cattle problems. Dipping was mentioned most frequently (by 100% of the groups) followed by diseases (83%) and then lack of/poor veterinary services (67%). Livestock owners were also asked more specifically about diseases. There was clearly some confusion between diseases, symptoms and disease vectors. The following table shows the diseases mentioned and their importance ranking.

Table 1. Importance ranking of different diseases.

	Rank 1	Rank 2	Rank 3	Rank 4
Diahorrea	50%	17%	17%	17%
Eyes	33%	67%		
Trypanosomiasis	17%			
Ticks		17%	17%	
Hooves			17%	33%
Bowels			17%	
Worms			17%	
Rashes				33%

As the table shows eye diseases and diarrhoea were ranked either 1st or 2nd most important by 100% and 67% of farmers. Trypanosomiasis was generally not considered a very important problem; it was only mentioned by one group. Similarly, tick-borne diseases (TBD) were not considered a major problem.

The relative unimportance of trypanosomiasis and tick-borne diseases, from the farmers perspective, is not surprising. The Government of Zimbabwe has financed and maintained a barrier of odour-baited targets and provided a heavily subsidised cattle dipping service for several decades. These services have, until recently, successfully controlled tsetse and tick-borne diseases in the area.

Farmer's perceptions regarding tsetse control: Dipping.- The groups were asked what they considered to be the advantages of dipping. All mentioned that dipping protects cattle from ticks and 67% mentioned that dipping also protects cattle from tsetse and other biting flies.

Problems with dipping were also discussed. A lack of chemicals and water shortages were mentioned most frequently; 50% of the groups also mentioned poor information concerning when dipping is due to take place.

All the groups of livestock owners felt that the cost of dipping is too high, particularly since the dipping services currently being provided are poor. At the time of the interviews the annual cost of dipping was just Z\$3.00/animal/year (£0.05). One group mentioned that there was an 8 month period in 1998 when there was no dipping. Most people continued to dip their animals when the costs increased because the service is seen to be beneficial and because they had no alternative but to pay.

Targets.- The advantages of targets mentioned were that they kill tsetse flies and that cattle maintain good health as a result of them. During the period when the target barrier was removed, a large proportion of the livestock owners surveyed said that cattle death and illness increased, although they were not always sure why.

Farmers were asked about their perceptions of the value of targets and were asked if they had to pay for them, how much they would be willing to pay. Two groups said that they could not afford to pay for targets and cannot even afford the current dipping fees. Another two groups were not able to answer the question at all; one group did not want to answer the question because they felt it would have implications for other livestock owners and said they could only answer if all VIDCO members were present. Most groups found the question difficult to answer because targets are considered the responsibility of the government and the idea of farmers paying for their maintenance was difficult to understand. However, when the question was phrased in terms of possible use of targets in other countries one group was able to put a value on them and said they were worth \$2 per head.

Because of the difficulties in getting farmers to value targets, they were asked to compare them to dips (i.e. which is more beneficial). Two groups said targets and dipping are of equal value and two groups were unable to answer. One group said that they could not compare the values because targets and dips are there for different reasons (targets are to kill tsetse flies and dips are for ticks and other biting insects). The final group said they would prefer to pay for dipping than targets.

In summary, farmers in Chikwizo A do not perceive Trypanosomiasis and TBDs to be major constraints to cattle production. The history of Government provision, and heavy subsidisation, of effective tsetse and tick control schemes has influenced farmer perceptions of the risk and cost of these diseases. Issues of cost-effectiveness and sustainability of the

different tsetse control methods are viewed as concerns for the Government, not for the individual livestock owners.

Cattle ownership, distribution and management practices in Chikwizo A

Cattle numbers and distribution.- A total of 2200 cattle were estimated as being present in the Chikwizo A ward and of these, households from Kanyoka, Nyamukacha and Nyamhasa villages own ~700, ~600 and ~300 animals respectively. Aerial photographs suggested that in 1997, farming activities within Chikwizo A ward were concentrated towards the western edge of the ward, with virtually no signs of agriculture within 4 km of either the eastern edge of the barrier or the Nyamasandzura and Rwenya rivers (Fig. 2). Dense forest predominated along the eastern edge of the barrier while the remaining areas were predominantly sparse woodland/bush. Ground surveys of kraals, undertaken in 1999, were in general agreement with the patterns derived from the aerial photographs with few kraals being found in the northern, eastern or southern margins of the ward.

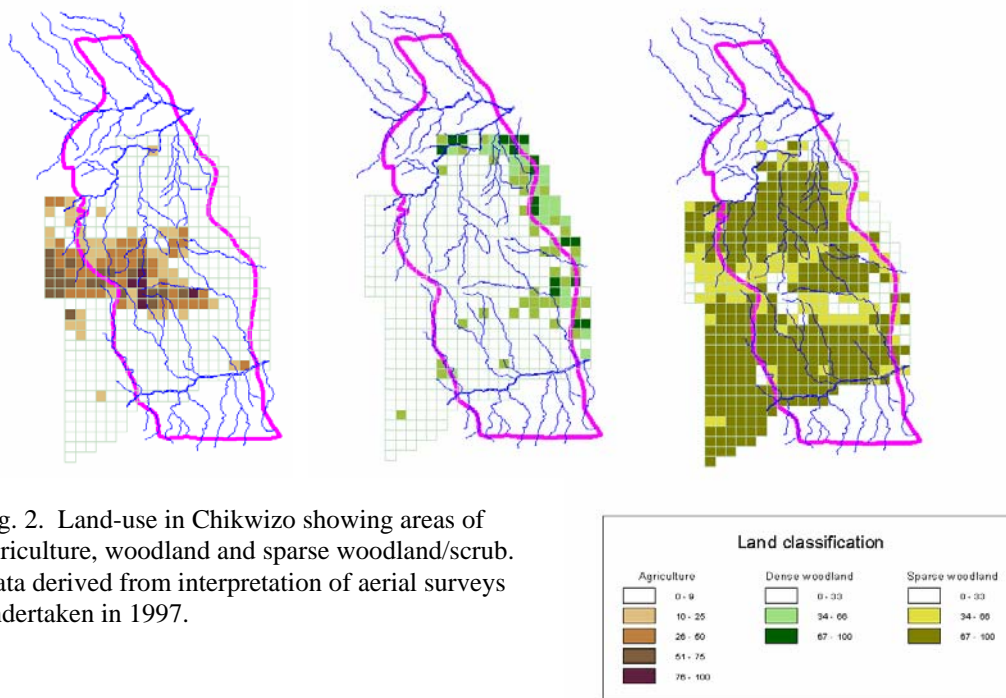


Fig. 2. Land-use in Chikwizo showing areas of agriculture, woodland and sparse woodland/scrub. Data derived from interpretation of aerial surveys undertaken in 1997.

Herd sizes and compositions.- The average household herd size, from a sample of 203 households, was 8.1 cattle and the percentage composition of the herds was 28% oxen, 7% bulls, 44% cows and heifers and 21% calves.

The herd size of 32 grazing herds located in their grazing areas in February 1999 ranged from a minimum of 2 to a maximum of 98 animals. The herd of 98 cattle belongs to one owner and is unusual in its size. The mean size of the grazing herds (excluding the exceptional large herd) was 17.7 cattle and the mean composition 25% oxen, 6% bulls, 48%

cows and heifers and 21% calves. The mean number of goats grazed together with cattle herds was 17.

Grazing and kraaling practices.- During the wet season, livestock are herded. This is generally done by adults on weekdays and by children at the weekends. Few households employ full-time herders. Nearly all livestock owners herd cattle and goats together. Cattle are let out of their kraals between 08:00 h and 10:00 h and return between 16:00 and 18:00 h. During the dry season livestock are not herded and were reportedly let out of their kraals earlier (05:00 – 06:00 h) and return anytime from 14:00 and 19:00 h. Cattle are rarely left out overnight because of the danger of stock theft. The majority of households said that they herd their own livestock but that herds often meet up in the grazing areas

There was a difference in opinion between groups concerning changes in grazing areas and patterns. Fifty percent felt that over the last 10 or 15 years there has been little change in grazing areas used. The other 50% felt that as a result of increases in the human and cattle populations, cultivated areas have increased and grazing areas have decreased. Cattle now have to go further to graze although there is still plenty of grazing land available. One group mentioned that previously cattle could be left to roam but now they have to be herded so that they do not go into cultivated areas.

Surveys of grazing herds showed that few were found >3 km from their kraals (Fig. 3); even in the late dry season the herds did not move any great distance from their night kraals (Fig. 4). The absence of people and cattle along the eastern edge of the ward is largely because people have been discouraged from living close to the Mozambique border due to various military activities related to Zimbabwe's war of Independence in the 1970s and raids by the RENAMO organisation in Mozambique in the 1980s. An extensive minefield still exists along the Zimbabwe-Mozambique border and people avoid grazing cattle in the area; during this study, one livestock owner reported losing stock in October 1999 due to cattle straying into the minefield.

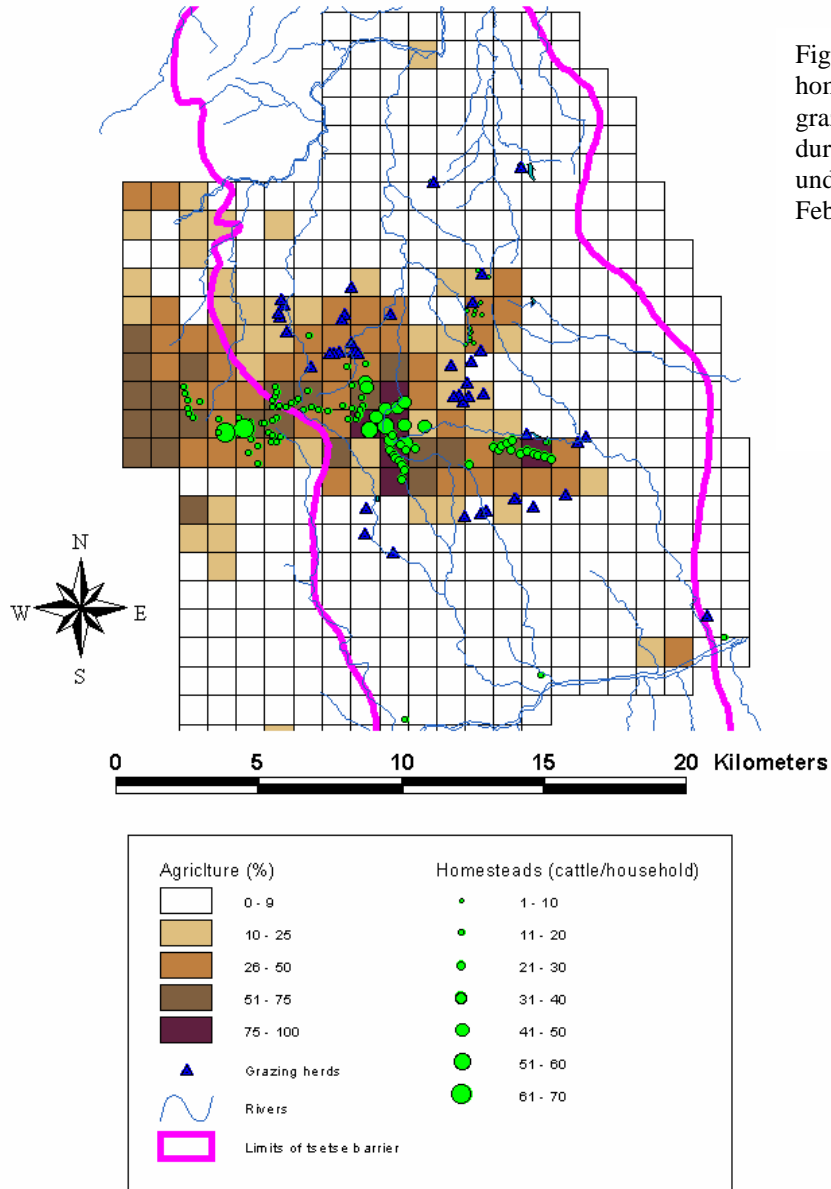


Fig. 3 Distribution of homesteads and grazing herds located during surveys undertaken in February 1999.

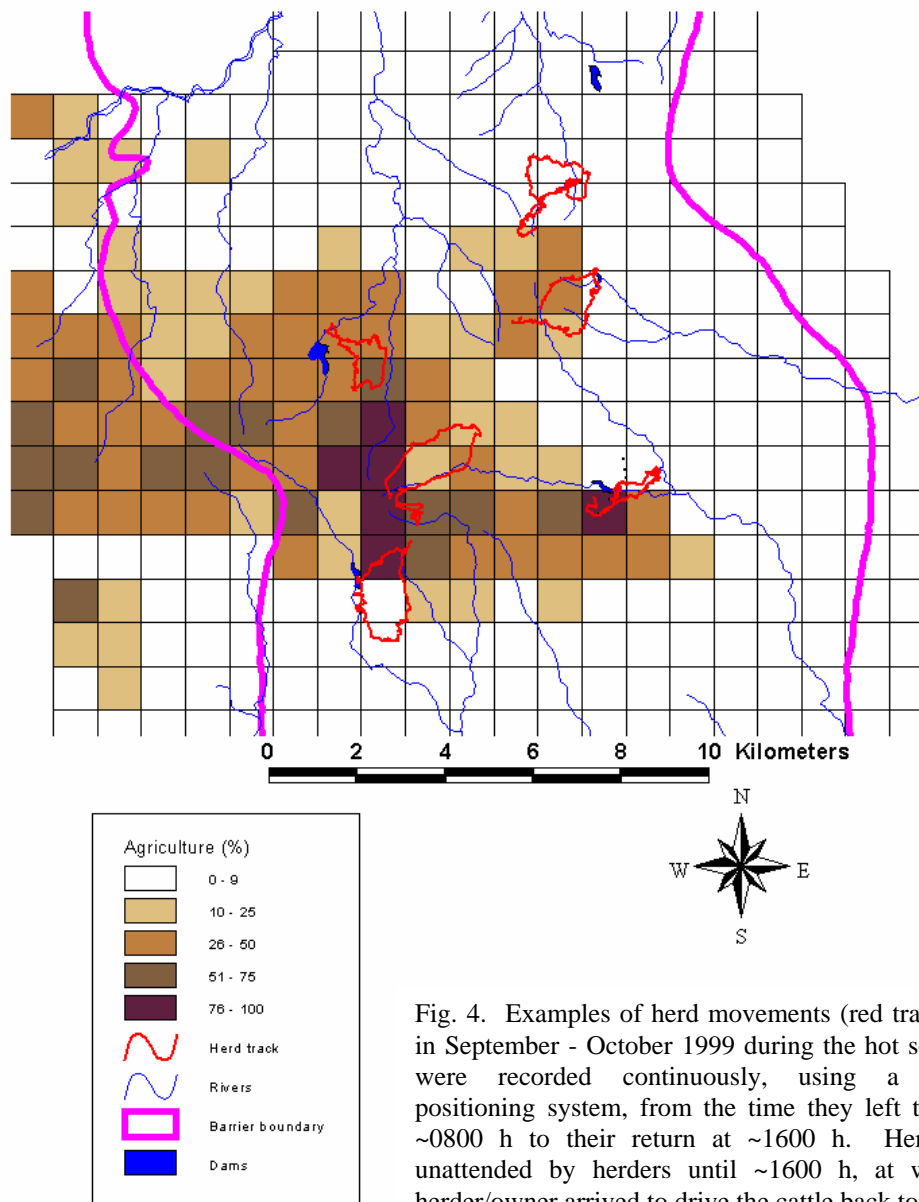


Fig. 4. Examples of herd movements (red tracks) recorded in September - October 1999 during the hot season. Herds were recorded continuously, using a geographical positioning system, from the time they left their kraals at ~0800 h to their return at ~1600 h. Herds were left unattended by herders until ~1600 h, at which time a herder/owner arrived to drive the cattle back to their kraal.

Simulation modelling

Insecticide-treated cattle were found in an area of *c.* 165 km² of the District (Fig. 5). When odour-baited targets were present they were deployed in 227 km² of the District - but the barrier extended to the north and to the south of the area in which cattle were treated with insecticide (Fig. 6). In the simulations carried out here it was assumed in each case that,

**Comparison of insecticide-treated cattle
and odour-baited targets as barriers to
reinvansion by tsetse
Mudzi; NE Zimbabwe**

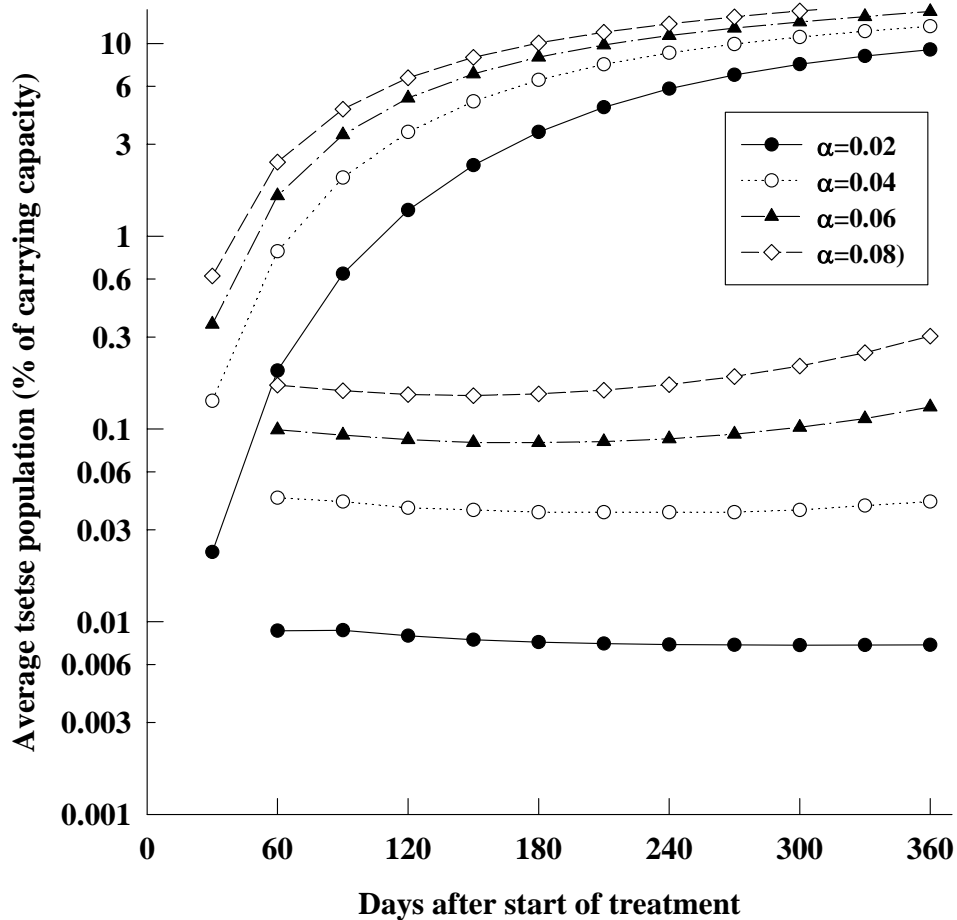


Figure 7. Predicted changes in the mean tsetse population in Mudzi District, NE Zimbabwe following the use of either insecticide-treated cattle (upper curves) or odour-baited targets (lower curves) as agents of tsetse control. Inset legend indicates the value of the diffusion coefficient in each case. A growth rate of 1.5% per day was assumed for all simulations.

When the target barrier was replaced with insecticide-treated cattle, the re-invasion from Mozambique was substantial (Fig. 9). In keeping with the findings of Warnes *et al.* (1999) the largest tsetse populations were also found close to the Mozambique border but it is clear that, if the insecticide-treated cattle trial had been continued any longer there would have been substantial losses of tsetse-free areas deeper into Zimbabwe.

0	0	0	0	0	0	0	0	0	0	1	4	11	35	57	72	82	89	93	96	98	99	99	
0	0	0	0	0	0	0	0	0	0	1	2	6	17	43	61	74	83	89	93	96	98	99	
0	0	0	0	0	0	0	0	0	0	0	1	3	9	29	45	61	74	83	90	94	96	98	
0	0	0	0	0	0	0	0	0	0	0	1	1	4	10	18	42	60	74	84	90	94	97	
0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	7	17	41	61	76	86	92	95	
0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	7	18	43	65	79	88	93	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	3	8	20	51	71	83	91	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	4	12	38	62	78	88	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	7	19	50	71	84	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	12	39	63	79	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	7	20	55	75
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	5	16	49	71
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	46	69	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	12	42	65	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	10	35	60	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	7	20	54	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	5	16	50	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	15	48	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	14	47	

Figure 8. Predicted tsetse distribution one year after the introduction of a barrier of odour-baited targets deployed at 4 km² along the Mozambique border in Mudzi District, NE Zimbabwe.

The simulations carried out in this study provide good description of what actually happened in the experimental use of baits (insecticide-treated cattle or odour-baited targets) in Zimbabwe. As such it appears that the model developed is a useful tool for predicting the outcome of tsetse control operations.

The present results suggest that a barrier of insecticide-treated cattle was unable to prevent re-invasion of tsetse because the cattle were unevenly distributed. In particular, most cattle were confined to a relatively small area of ~50km² leaving large areas to the east and along the two main rivers, largely cattle free. Consequently the barrier was not only narrower than intended, but there were also cattle-free corridors running through it.

25	32	40	48	56	63	69	75	79	83	87	90	92	94	96	97	98	99	99	99	99	99	99	99
25	32	40	48	56	63	69	74	79	82	85	88	91	93	95	97	98	98	99	99	99	99	99	99
24	31	39	47	55	61	67	72	76	78	81	84	88	91	93	95	97	98	98	99	99	99	99	99
22	29	37	44	51	58	64	68	70	71	73	77	82	87	91	93	96	97	98	99	99	99	99	99
20	26	33	40	47	53	58	62	62	64	66	69	74	80	86	91	94	96	97	98	99	99	99	99
17	22	29	35	41	47	51	54	55	56	57	59	64	70	80	86	91	94	96	98	98	99	99	99
14	18	24	29	34	39	43	46	46	47	47	46	49	57	71	80	87	92	95	97	98	99	99	99
11	14	18	22	26	29	31	35	36	37	35	37	41	48	58	72	83	89	94	96	98	98	99	99
8	10	13	15	17	18	16	22	25	28	27	29	34	40	49	61	77	87	92	95	97	98	99	99
5	6	8	8	7	7	7	9	11	16	18	22	27	34	43	55	73	84	90	94	96	98	99	99
2	2	3	4	3	3	3	4	5	6	9	15	21	28	38	51	69	81	88	93	95	97	98	98
1	1	1	1	1	1	1	2	3	3	4	7	14	22	32	49	64	76	85	91	94	97	98	98
0	0	0	0	0	0	1	1	2	1	2	4	7	13	22	40	55	70	81	88	93	96	98	98
0	0	0	0	0	0	0	0	1	1	1	2	4	8	15	26	38	59	75	86	92	95	97	97
0	0	0	0	0	0	0	0	0	0	1	1	3	6	12	19	29	45	69	83	91	95	97	97
0	0	0	0	0	0	0	0	0	0	1	1	3	6	11	18	27	41	67	82	90	94	97	97
0	0	0	0	0	0	0	1	1	1	1	2	4	8	13	19	29	44	69	83	90	94	97	97
0	0	0	0	0	0	1	1	2	2	3	4	7	12	18	25	38	58	75	85	91	95	97	97
0	0	0	0	1	1	2	4	4	5	7	9	15	21	27	36	54	69	80	87	92	95	97	97
0	0	1	1	2	3	5	7	9	13	18	23	30	38	46	55	66	76	84	90	93	96	97	97
0	0	1	1	2	4	6	10	14	19	26	33	41	50	58	66	74	81	87	91	94	96	97	97
0	1	1	2	3	5	8	12	17	24	32	40	48	57	65	72	79	84	89	92	95	96	97	97
0	1	1	2	3	6	9	14	20	27	35	44	53	61	69	76	81	86	90	93	95	96	97	97
0	1	1	2	4	6	10	15	21	29	37	46	55	63	71	77	83	87	90	93	95	96	97	97
0	1	1	2	4	7	10	16	22	30	39	48	56	64	72	78	83	87	90	93	95	96	97	97
0	1	1	2	4	7	11	16	22	30	39	48	56	65	72	78	83	87	90	92	94	96	97	97
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0	1	1	2	4	6	10	15	21	29	37	46	54	62	69	75	80	84	87	89	91	93	95	95
0	1	1	2	4	6	9	14	20	28	36	44	52	60	67	72	77	80	83	86	88	91	93	93
0	1	1	2	3	6	9	13	19	26	34	42	49	57	63	68	72	75	77	79	82	85	89	89
0	1	1	2	3	5	8	12	17	24	31	38	46	53	58	63	65	66	66	68	71	76	83	83
0	0	1	2	3	4	7	11	16	21	28	35	42	48	53	56	56	54	49	48	51	59	73	73

Figure 9 Predicted tsetse distribution one year after the introduction of the use of insecticide-treated cattle as a barrier against tsetse reinvasion from Mozambique. Mudzi Distric, NE Zimbabwe.

The cattle-management practices found in the Mudzi district are fairly typical of tsetse-affected areas of NE Zimbabwe. Moreover, the patchy distribution of people and cattle is also fairly typical. Consequently, one would expect to observe the same results with the use of insecticide-treated cattle elsewhere in Zimbabwe. The present results suggest that tsetse control operations aimed at preventing re-invasion in Zimbabwe should be based on the use of insecticide-treated targets rather than insecticide-treated cattle.

Experience has shown that, properly managed and appropriately applied, insecticide-treated cattle and odour-baited targets are powerful weapons in the arsenal of tsetse control

weapons. But, as with all such weapons, their indiscriminate use, without due regard to potential levels of re-invasion and without an interactive approach, will often be disastrous both from a veterinary and from an economic point of view.

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Insecticide-treated cattle for tsetse control in Tanzania: 1. The power and the problems.

SUMMARY

Analysis is presented of the results of two Tanzanian tsetse control campaigns involving the use of insecticide-treated cattle. Between 1991 and 1996, following the introduction of widespread dipping in the Kagera Region, trypanosomiasis declined from >19,000 cases to <2400 and deaths from >1000 to 29. On four ranches in the region, tsetse have been almost eliminated and trypanosomiasis prophylaxis is no longer used. Similarly aggressive use of pyrethroids on Mkwaja Ranch (Tanga Region) has not had such dramatic effects. Tsetse and trypanosomiasis are still common, despite high levels of prophylaxis and the deployment of *ca.* 200 odour-baited targets. The difference in the results is attributed to a combination of the much smaller area covered by treated animals at Mkwaja, a greater susceptibility to re-invasion and a more suitable habitat for the flies. We need a better understanding of the dynamics of the use of insecticide-treated cattle before we can predict confidently the outcome of particular control operations.

Introduction

Current trends in the control of tsetse (*Glossina* spp.), strongly influenced by donors, envisage a reduced role for central government. Ownership of livestock is seen as a commercial enterprise and the costs of controlling diseases such as trypanosomiasis should therefore be borne by the stockowner. Thus, the Republic of Zambia (1996) plan for tsetse control and rural development quotes the *Zambian Agricultural Sector Investment Programme* document as stating that: "Private sector and community participation in activities such as target deployment, maintenance etc. will form the basis for all field level interventions. Drugs used to control the disease will be obtained through the private sector at full cost to the livestock holder."

This type of policy, typical of those being imposed on African countries as part of larger economic structural adjustment programmes, has implications for the entire approach to tsetse and trypanosomiasis control because of the resulting change of scale. Methods such as aerial and ground spraying and the sterile insect technique (SIT), which may be appropriate over large areas, are inappropriate when applied locally. If, for example, stockowners living in a tsetse area spray 100 ha with DDT they may well kill many tsetse, but re-invasion will be such that disease levels in their cattle will be unaffected. In short they will simply be wasting time and money.

Policy makers may have understood this point but there is an implication in their proposals that there are alternative methods of tsetse control which can be used successfully on a small scale. The wording of the *Zambian proposal* suggests that drug treatment of the disease and/or bait methods (see below) of tsetse control are what the donors have in mind. Indeed, if ground and aerial spraying and SIT cannot be used, it is hard to see what other options exist for disease control. It is therefore important to assess just how well these alternative methods have worked in the past and are likely to work if they are applied by small-scale stockowners.

A detailed discussion of the pros and cons of a complete reliance on the use of drugs is beyond the scope of the present paper but is noted that: i) It is quite possible to keep cattle alive on such drugs, even in areas of high trypanosomiasis challenge. ii) Given the progressive decline in the efficacy of tsetse control programmes in most tsetse infested areas in Africa, stockowners rely increasingly on drugs - almost all of which they pay for themselves. iii) Trypanocidal drugs have no direct effect on tsetse. In the event of the development of drug resistance, the trypanosomiasis problem will therefore return. In that event, and given the exigencies referred to above, bait methods appear to be almost the only remaining options for disease control.

Tsetse control currently relies heavily on two bait systems where flies are attracted to, and treated at, point sources. The first is traps and targets, which are composed of fabric sheets treated with insecticide which kills tsetse on contact. The second is insecticide-treated livestock. Both systems have the advantage of causing little direct damage to the environment (Vale, 1993) and of being very effective if applied properly in the appropriate circumstances.

The low reproductive rate of tsetse makes it possible to use densities of *ca.* 4 km⁻² of evenly spaced odour-baited targets to provide good control, and sometimes eradication, of tsetse populations within two years (Vale *et al.*, 1988; Dransfield *et al.*, 1990; Willemsen,

1991). Insecticide-treated cattle have been used, with different degrees of success, to control tsetse and trypanosomiasis. Such operations have been carried out in Zambia (Chizyuka & Liguru, 1986), Zimbabwe (Thomson *et al.*, 1991), Tanzania (Fox *et al.*, 1991, 1993), Kenya (Stevenson *et al.*, 1991), Burkina Faso (Bauer *et al.*, 1992, 1995, 1999) and Ethiopia (Leak *et al.*, 1995).

From the point of view of policy makers, the major advantages of bait methods are that they are relatively cheap (Barrett, 1994) and simple to apply. They could therefore, in principle, be carried out and paid for by stockowners themselves. Just as highly localised ground or aerial spraying is a waste of time (Hargrove, 1998), however, it is equally senseless for farmers in the middle of an extensive tsetse belt to deploy insecticide-treated targets around their houses, or to apply insecticide to small numbers of cattle.

Words such as ‘small-scale’, ‘localised’, ‘small numbers’ and ‘extensive’ have been used above in a deliberately vague fashion because there has been little consideration of the effects of scale on the efficacy of various tsetse control methods in general, and on bait methods in particular. Nor do we know how local climate and vegetation affects the outcome of localised tsetse control operations. We do not therefore know the circumstances under which it is worth a livestock owner attempting to control trypanosomiasis using bait methods or, alternatively, where this is a waste of time, effort and money.

Activities

The outcome of two tsetse control campaigns in Tanzania involving the use of insecticide-treated cattle were analysed. The very different outcomes of the two campaigns suggest that the above concerns are of practical importance.

Outputs

Karagwe District (Kagera Region; North-west Tanzania)

Situation in 1992. The assumed tsetse situation in the Bukoba and Karagwe Districts in 1992 is shown in Fig. 1 (Kagera Regional Office, 1992). Between 1988 and 1993 more than 16,000 cattle were infected annually with trypanosomiasis and 460 - 990 cattle died of the disease annually (25 - 50% of the total deaths due to all tick-borne diseases). There were 24 new cases of human sleeping sickness reported in the Kagera Region between 1983 and 1992. This serious situation prevailed despite the huge amounts of money spent in the past on bush-clearing, game destruction and ground and aerial spraying of insecticides. These efforts had generally not been successful due to re-invasion of areas which had not been settled following the application of tsetse control measures.

Situation after 1992. Following trials involving the use of pyrethroids on livestock in Zimbabwe (Thomson M., 1987; Thomson J. & Wilson, 1992a, b), on Mkwaja Ranch in the Tanga Region (Fox *et al.* 1993) and elsewhere (Thomson, J. *et al.*, 1991), the Kagera Livestock Development Programme (KALIDEP) began trials of their own in the Kagera Region in 1991. By 1997 the number of cases of animal trypanosomiasis had declined from 19,300 to 2383 (Fig. 2) and deaths from 730 to 29. The number of deaths had reached a peak of over 2000 in 1986. These figures represent numbers of animals showing clinical symptoms of trypanosomiasis rather than microscopic or biochemical diagnoses. Moreover,

some cases of trypanosomiasis will have been undiagnosed or unreported, and the under-reporting may have differed from year to year. Nonetheless, there has obviously been a major decline in true levels of trypanosomiasis in the past decade, and there have been no reported cases of sleeping sickness in the Bukoba or Karagwe Districts since 1992.

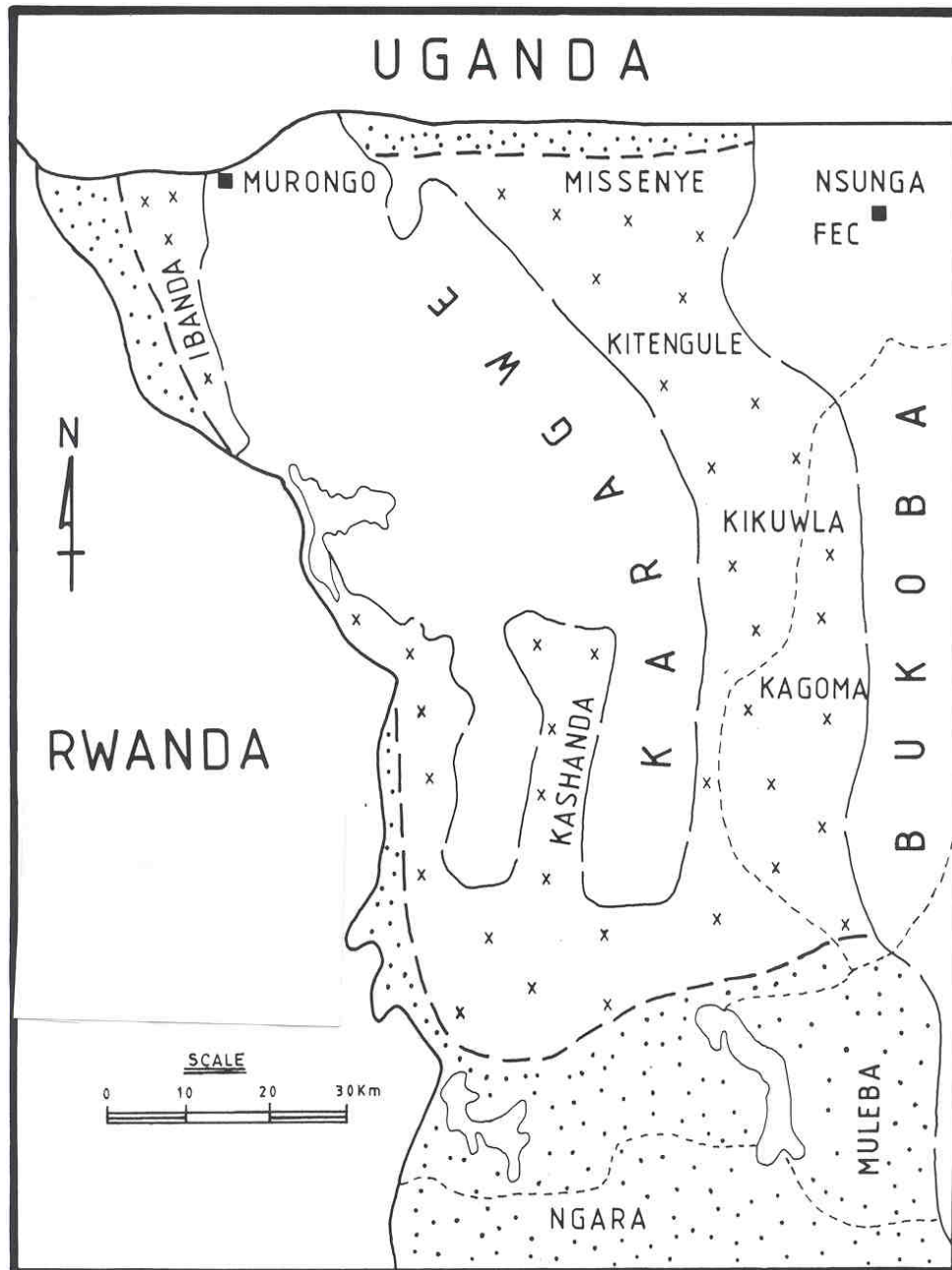


Fig. 1 Probable distribution of tsetse in Bukoba and Karagwe Districts, Kagera Region, Western Tanzania. The four NARCO State Ranches are Missenye, Kitengule, Kikulwa and Kagoma. Prior to 1992 tsetse were abundant in all areas indicated as low density.

These changes in trypanosomiasis are strongly correlated with the introduction of pyrethroids as a means of controlling tsetse and other biting flies. The biggest user in the Kagera region is the National Ranching Company (NARCO), who first used Decatix® on Kitengule Ranch in 1991/92. At the same time the Ranch management decided to stop using Samorin®. Not surprisingly, since the animals had no protection against infection, there was an increase over the next two years in the number of cattle requiring trypanocidal treatment drugs - Berenil®, Ethidium® or Novidium® (Fig. 3) - but the requirement even for these drugs has decreased consistently since 1994.

There was actually a decrease on Kitengule Ranch in the requirement for these drugs in 1990/91, before pyrethroids had been introduced, but when the cattle were still on Samorin® (Fig. 3). This may be related to the fact that KALIDEP had started using pyrethroids in the neighbourhood of the ranch during that year. Possibly, also, owners of indigenous cattle may have been ahead of both KALIDEP and the ranch owners in their appreciation of the importance of chemicals like Decatix®. There is evidence that some stockowners started importing the chemical from Uganda as early as 1988 (Okali *et al.*, 1997).

A particularly impressive change in the tsetse population was seen in a refugee camp (Burigi TCRS) in 1993-94 following the regular dipping of 6000 head of cattle in the area with deltamethrin®. The tsetse population declined exponentially over a 12-month period (Fig. 4a). Trypanosomiasis levels declined more slowly for the first six months then crashed to zero and remained there for the remainder of the study period (Fig. 4b). The owners and their cattle have since returned to Rwanda and the area has been re-invaded by tsetse.

The reduction in trypanosomiasis in Kagera has occurred despite a fall in expenditure on trypanocides from US\$ 257,000 to US\$ 5700 (52 to 9 million Tshs; KALIDEP, 1996; p. 117). Spending on pyrethroids has increased from zero to US\$ 116,000 (67 million Tshs at the 1996 official exchange rate) over the same period (Fig. 2). There has thus been a substantial saving in terms of foreign exchange. Pyrethroids are, moreover, used also as acaricides, which would continue to be used even if trypanosomiasis disappeared completely. Only part of the pyrethroid cost should thus be attributed to the trypanosomiasis problem, which is now so small that some ranches have started to use cheaper acaricides which do not kill tsetse. Finally, no allowance has been made for the improvements in cattle productivity and condition resulting from the removal of trypanosomiasis (*cf* Fox *et al.*, 1993) and the cessation of Samorin treatment.

Although detailed tsetse surveys have not been carried out in the Kagera Region it seems that *Glossina morsitans centralis* Machado and *G. pallidipes* Austen have been eradicated over a large proportion of Bukoba and Karagwe (Fig 1). On the ranches, certainly, tsetse numbers are now so low that they do not pose a threat to herds of animals routinely treated with pyrethroids. On Kitengule, for example, no Samorin® has been used since 1992 but only 10 animals were treated for trypanosomiasis in 1996-1997, compared with >10,000 in 1988 - 1990. Similar changes have occurred on the other ranches and interviews with stockowners in areas near the ranches likewise indicate a sharp decline in trypanosomiasis challenge. In almost every case owners have been using Decatix® for extended periods since 1990.

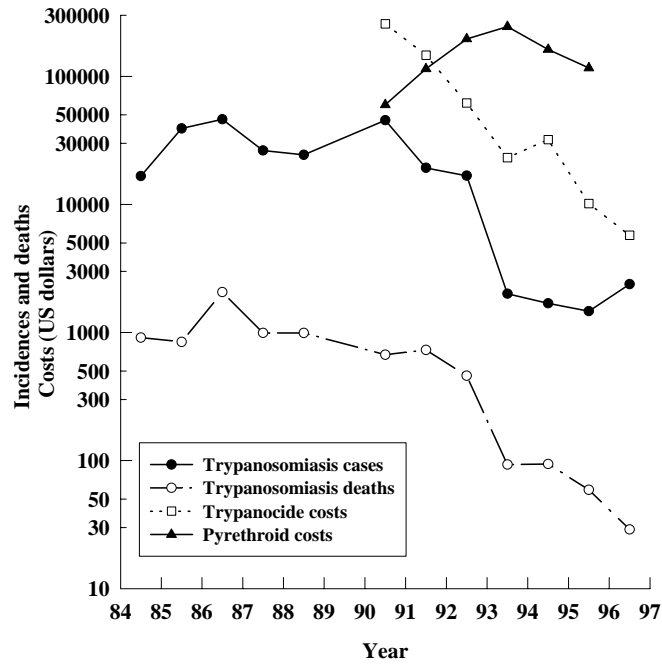


Fig. 2 Trypanosomiasis prevalence and spending on trypanocidal drugs and pyrethroids in Kagera Region, Western Tanzania.

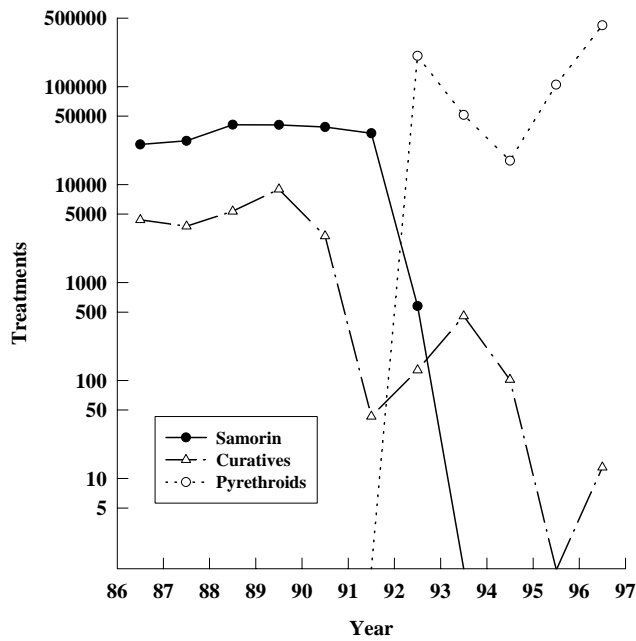


Fig. 3 The consumption of trypanocidal drugs and pyrethroids on Kitengule ranch, Karagwe District, Western Tanzania.

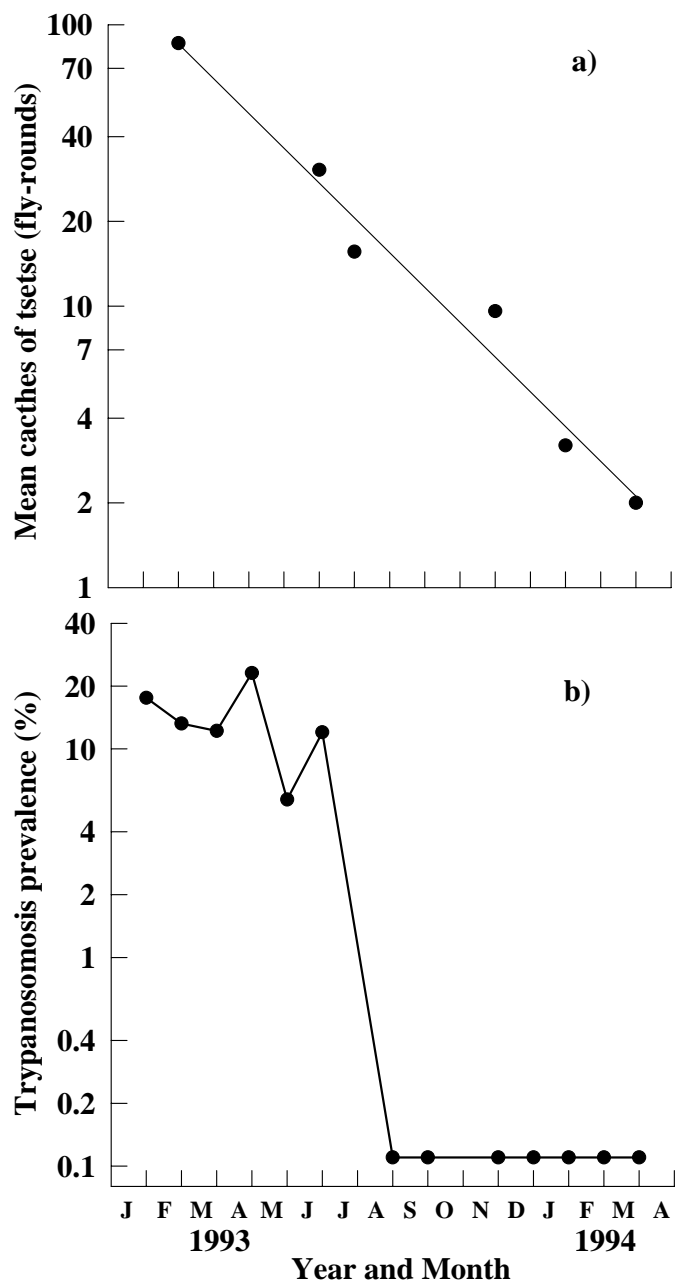


Fig. 4 a) Trap catches of tsetse flies *G. m. centralis*; b) trypanosomiasis prevalence following the dipping of cattle with pyrethroids. Burigi TCRS, Bukoba District, Kagera Region, Western Tanzania.

Mkwaja Ranch (Tanga Region; North east Tanzania)

The impact of insecticide-treated cattle on the tsetse and trypanosomiasis situations has been quite different in the Tanga Region, as exemplified by the situation on Mkwaja Ranch (Figs. 5 - 6). Following the introduction of deltamethrin® dipping in mid-1989 Fox *et al.* (1993) saw a decline in populations of *G. m. morsitans* Westwood, *G. pallidipes* and *G. brevipalpis* Newstead, and a dramatic improvement in herd health, including a decrease in levels of trypanosomiasis. Contrary to the Kagera situation, however, trypanosomiasis did not disappear entirely; 11 animals died of trypanosomiasis in 1990/91 despite continuing Samorin® prophylaxis.

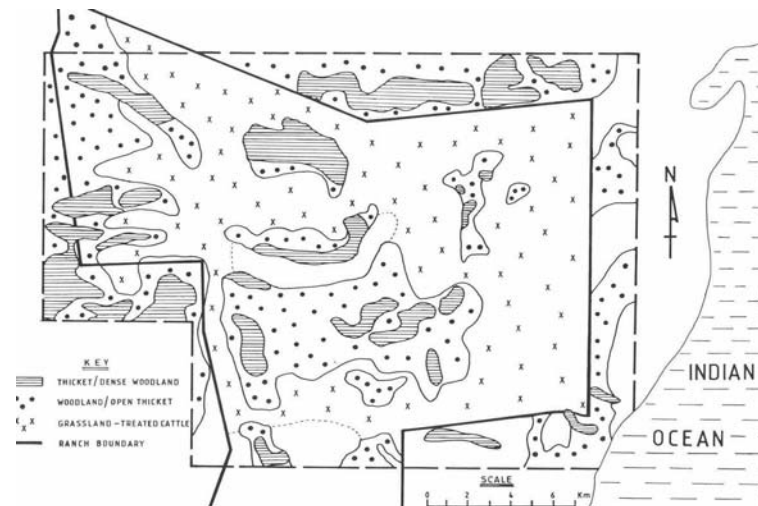


Fig. 5 Mkwaja Ranch, Tanga Region, Eastern Tanzania.

The situation has changed little since then (Fig. 6). Trap catches (mostly *G. pallidipes*) since 1993 have been fairly constant at *ca.* 5 tsetse per day, although improved methods produced daily trap catches in excess of 200 in 1999 (Torr, unpublished). Samorin® and Berenil® usage (Fig. 6c) reflects the trypanosomiasis situation - which is static, despite deltamethrin® dipping, large spending on Samorin® and Berenil®, and the deployment of *ca.* 200 odour-baited targets. Thus, while tsetse control operations seem to have been as well executed on Mkwaja as in Kagera, the results have not been nearly as dramatic.

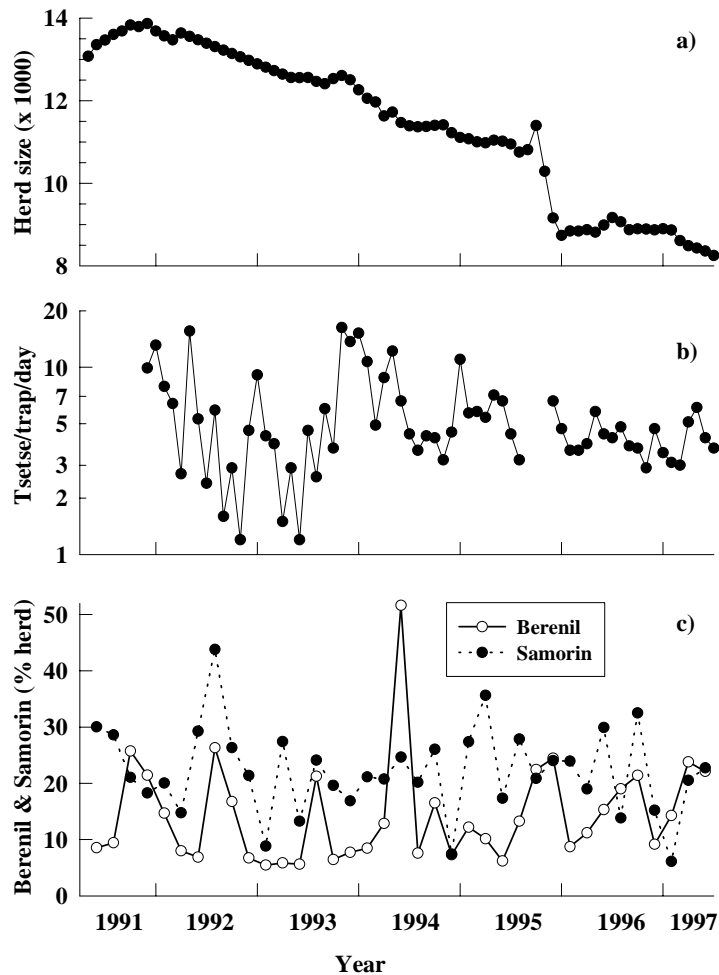


Fig. 6 The trypanosomiasis situation on Mkwaja Ranch, Pangani, Tanga Region, Eastern Tanzania. a) Herd size. b) Trap catches of tsetse flies (mostly *G. pallidipes*) from odour-baited Ngu traps. c) Consumption of trypanocidal drugs.

Experience from other pour-on trials

The two Tanzanian operations provide an interesting but disturbing contrast. Given only the results from the Kagera Region one might conclude that insecticide-treated cattle provide a panacea for low-cost tsetse eradication. The results from Mkwaja warn that the matter is not entirely clear-cut. Baylis & Stevenson (1998) cite other examples of pour-on control operations which have encountered difficulties. They themselves found that, relative to a control area, the application of 50,000 doses of Spot On™ to cattle at Dakabuku, Galana Ranch, Kenya, produced little effect on the apparent densities of two species of tsetse. The reduction in trypanosomiasis was, however, more marked and they cited similar results from the work of Leak *et al.* (1995) in Ethiopia. An attempt to use treated cattle as a barrier to tsetse re-invasion from Mozambique into north-eastern Zimbabwe was also unsuccessful. Warnes *et al.* (1999) treated 5400 cattle at two-weekly intervals in an area of 428 km², but the area was nonetheless rapidly invaded and there was a serious deterioration in the disease situation.

It is important to understand precisely why fly populations were poorly controlled in some areas, but more successfully elsewhere, such as in Zimbabwe (Thomson *et al.*, 1991) and in several campaigns in Burkina Faso (Bauer *et al.*, 1992, 1995, 1999). While we are not in the position to answer this question unequivocally in each of the cases cited, a comparison of the two Tanzanian studies provides some pointers to what may be important factors.

Possible reasons for the differences in pyrethroid efficacy in Kagera and Tanga Regions

The use of pyrethroids in Kagera has probably been particularly successful because there has been prolonged and regular dipping on the ranches, which cover a large proportion (> 2000 km²) of one arm of the local tsetse belt. There has also been widespread, though less methodical, use of pyrethroids in areas adjacent to the ranch. Finally, the area is protected from re-infection from the west by the Karagwe Escarpment and from the east by heavy settlements that are tsetse-free. Re-infection can thus come only from two directions, which makes it easier to keep the region secure once the local tsetse population has been removed.

In contrast, the area grazed by treated cattle at Mkwaja is < 100 km² (Figs. 5 and 6). In areas adjacent to the ranch there is no organised dipping, and pyrethroids are less widely used, so that the ranch is subject to re-invasion from all sides except from the sea to the east. Re-invasion was similarly cited by Leak *et al.* (1995) as a possible reason for failure to eradicate tsetse, and hence trypanosomiasis, from an area of *ca.* 200 km² in the Ghibe valley of Ethiopia. The area treated by Baylis & Stevenson (1998) was smaller yet than Mkwaja and it is therefore scarcely surprising that there was at best a modest effect on the tsetse population.

The bigger reductions in tsetse number in the pour-on operations of Bauer *et al.* (1992, 1995) may be due in part to the larger areas involved (500 – 1000 and 1400 km² respectively). Bauer *et al.* (1999) did effect > 90% decreases in apparent tsetse densities in an area of only 400 km² but, in addition to treating up to *ca.* 7000 cattle with insecticide, they also deployed 1500 insecticide-treated targets in the area. We do not know, therefore, the relative importance of the targets and the treated cattle in the resulting reductions in fly populations and disease levels.

The study area used by Warnes *et al.* (1999) was approximately the same size as that of Bauer *et al.* (1999) – but tsetse control using treated cattle alone was considerably less successful in the former situation. Odour-baited targets at a density of 4 - 5 targets km⁻² did, however, provide an effective barrier prior to the treated-cattle trial, and targets were used to retrieve the situation after that trial had ended.

Differences in tsetse control efficacy between different programmes may not be entirely due to levels of re-invasion. Indeed it is difficult to assess the importance of this factor because none of the works cited produced quantitative information regarding the levels of tsetse in areas surrounding the treatment sites. In the Zimbabwe barrier trial, Warnes *et al.* (1999) point out that, while the mean density of treated cattle was at the level recommended for such an operation (Bauer *et al.*, 1992), the patchy cattle distribution reduced their efficacy.

In the case of Mkwaja, maps of vegetation and cattle distribution (Fig. 5) show that, even on the ranch, there are extensive thickets which are not penetrated by the treated cattle but which harbour populations of warthog, bushpig and other favoured tsetse hosts. The

Tanga climate, hotter and wetter than in the area of the NARCO ranches in Karagwe, is also probably more favourable for tsetse. The higher temperatures ensure optimal birth rates, and the high humidity should ensure low death rates.

Practical conclusion regarding the Tanzanian campaigns

Pyrethroids have been applied regularly, for nine years, to between 8000 and 13,000 animals on Mkwaja Ranch and the trypanosomiasis problem is so severe that frequent treatments with Samorin® and Berenil® are still required (Fig. 7c). There is therefore every reason to suppose that the use of pyrethroids on a smaller scale in ecologically similar parts of Tanga Region would be even less successful. It would therefore be unwise for small-scale livestock keepers in that area to spend money on pyrethroids if their sole intention is to reduce trypanosomiasis levels in their cattle. There is thus an urgent need for research into the question of what livestock keepers in the region can do, on their own account, to combat the trypanosomiasis problem.

The way forward

Analysis of the studies cited above, and of the present results from Tanzania, suggests several factors which could affect the outcome of tsetse control campaigns involving the use of treated cattle: i) Scale effects and, particularly, rates of re-invasion. ii) The topology of the treated area and, particularly, of the untreated tsetse habitat in and around it. iii) The ecological suitability of the treated (and surrounding) area for tsetse. The ratio of game to livestock and, hence, the proportion of blood-meals taken from livestock should affect success, but this ratio was unknown in the present instance.

When the technique is used by small-scale cattle owners other factors will also become important: i) Herd structure and size. ii) Cattle management practices and, hence, tsetse-cattle contact. Practices vary enormously between pastoralists, ranchers, and keepers of zero-graze animals. iii) Ability and willingness of stockowners to buy and use insecticides.

Studies currently being undertaken in Zimbabwe and Tanzania aim to quantify the effects of as many as possible of the above variables. These data are being used to develop predictive models to describe the relationship between cattle distribution, tsetse-cattle contact and tsetse population dynamics. In particular, the models investigate the effects of scale on rates of tsetse control and of re-invasion. Computer modelling already carried out supports the conclusion that the use of treated cattle in areas of about the size of Mkwaja Ranch may be expected to face problems due to re-invasion (Vale *et al.*, 1999). The continuation of experimental and theoretical studies of this type is of obvious importance if we are to understand fully the limits of the power of insecticide-treated cattle as agents for trypanosomiasis control.

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Insecticide-treated cattle for tsetse control in Tanzania: 2. Simulation models of tsetse control operations at Mkwaja Ranch

SUMMARY

A simulation model is used to predict the effect of tsetse control campaigns involving the use of insecticide-treated cattle on Mkwaja Ranch, Tanzania where insecticide-treated cattle were used to achieve *c.* 90% control of the tsetse population. The model assumed diffusive movement and logistic growth in tsetse populations and daily population changes were modelled using Excel spreadsheets with macros written in Visual BASIC. The level and the time course of this control process were well fitted by the present simulation.

Control could have been improved by splitting the herds into smaller units, but the use of insecticide-treated cattle by themselves would never have solved the disease problem. Targets deployed throughout the ranch, and in a barrier of depth 3-km outside the ranch, would reduce the tsetse population to 0.03% of its carrying capacity. It is concluded that properly managed and appropriately applied, insecticide-treated cattle and odour-baited targets are powerful weapons in the arsenal of tsetse control weapons. But, as with all such weapons, their indiscriminate use, without due regard to potential levels of re-invasion and without an interactive approach, will often be disastrous both from a veterinary and from an economic point of view.

Introduction

In a recent paper Hargrove *et al.* (2000) reviewed the use of insecticide-treated cattle as a tsetse control option. Cattle have been treated with pyrethroid insecticides to good effect in Tanzania (Fox *et al.*, 1993) and elsewhere in Africa (Chizyuka & Liguru, 1986; Thompson *et al.*, 1991, 1992 a, b; Bauer *et al.*, 1992, 1999a, b). The results have, however, been varied and there are examples where the use of insecticide-treated cattle has not achieved the desired goal (Leak *et al.*, 1995; Warnes *et al.*, 1999; Hargrove *et al.*, 2000). The most likely problem lies in the number and the density of the cattle population. It was argued that the differences in effect had much to do with the size and shape of the area treated and the population size and density of the population of treated cattle. If the area treated is small and, particularly, if it is surrounded by tsetse infested areas it is likely that re-invasion pressure will prejudice the tsetse control efforts. The approach in these arguments was, however, entirely qualitative.

The aim of the present study is, firstly, to provide a quantitative analysis of various tsetse control operations which have involved the use of insecticide-treated cattle. Thereafter the hope is that, having provided an adequate description of past operations, it will be possible to predict the outcome of planned operations before they are carried out. In particular the aim was to arrive at the point where it will be possible to use given information on cattle and tsetse distribution to predict the effect, on the tsetse population, of treating some or all of these cattle with insecticide.

Studies of past operations

The results of tsetse control operations undertaken at Mkwaja Ranch, Tanga Region, NE Tanzania are modelled. The ranch, which in recent years has had populations of up to 12,000 cattle, has had a long history of trypanosomiasis problems. Various approaches have been used in efforts to remove the tsetse problem and none has been entirely successful. In 1989 it was decided that the ranch should try dipping all of the stock using a pyrethroid. Records were kept of the changes in disease prevalence, trypanocidal drug use and catches of tsetse in odour-baited traps after the initiation of the control measure.

Activities

Cattle density and distribution

Monthly estimates of the numbers of cattle held at each of the ranch's bomas and the numbers of tsetse caught from survey traps were collected from the records of Mkwaja ranch. The position of bomas, dip tanks, watering points, tsetse traps and the ranch boundaries were recorded using a geographical positioning system (GPS; Garmin 12XL, Garmin, Romsey, UK).

The grazing ranges of the herds were estimated by various methods. First, the farm and boma managers were interviewed. Second, the ranch was surveyed to locate herds as they grazed. The locations of all herds located during the survey were recorded using a GPS and the herdsmen accompanying each herd were interviewed to determine, amongst other things, from which boma they had travelled. Lastly, herds were tracked continuously using a

GPS. Herdsmen were issued with a GPS which they wore on their belts for the day. The GPS was programmed to record the location at two-minute intervals. None of the herdsmen had seen a GPS before and they were not told that the device could record their position.

The data were collated into a Geographical Information System (GIS) using Arcview (ESRI, Aylesbury, UK). In addition, the roads, rivers and vegetation types indicated on 1:50 000 scale maps of the Mkwaja area (Government of Tanzania) were digitised and incorporated into the GIS.

Modelling

Changes in tsetse populations were modelled in the manner first suggested for tsetse studies by Williams *et al.* (1992), using the Fisher equation:

$$\frac{\partial \rho(x,t)}{\partial t} = \alpha \nabla^2 \rho(x,t) + r\rho(x,t)[1 - \rho(x,t) / K] \quad (1)$$

which is derived assuming that tsetse populations move by diffusion and grow logistically.

The equation defines the instantaneous changes in population density $\rho(\mathbf{x},t)$ at any point \mathbf{x} in the two-dimensional plane, and at any time $t \geq 0$, for a population with predefined carrying capacity K and rates of growth r and movement α . If an additional mortality rate (δ) is imposed on the population then the growth rate and carrying capacity become $r^* = r(1 - \delta/r)$ and $K^* = K(1 - \delta/r)$ respectively and the Fisher equation is as above with r^* substituted for r and K^* substituted for K .

There is no known analytical solution to the Fisher equation. We can, however, approximate the changes occurring over small finite time steps in a grid whose mesh we can define as we wish. This is most conveniently done using a spreadsheet whose cells are taken to represent blocks of land. The model has been used recently in modelling rates of re-invasion of cleared areas (Hargrove, 2000) where the procedure is fully described in full. In summary, suppose we define a block X of country by an $n \times n$ lattice where each cell $X(i,j)$ ($i = 1,n; j = 1,n$) is equivalent to a (1 x 1) km square. For any square $X(i,j)$ located in the interior of the block suppose the population at time t is $N_t(i,j)$. One unit of time later this population (and indeed the population in each cell of X) will have grown, due to the birth and death processes and to movement, such that:

$$N_{t+1}(i,j) = N_t(i,j).r.(1 - (N_t(i,j)/K)) + N_t(i,j) + (\alpha((N_t(i,j-1) + N_t(i-1,j) + N_t(i,j+1) + N_t(i+1,j)) - 4.N_t(i,j))) \quad (2)$$

(where the components due to growth and to movement are shown on the first and second line of the equation respectively). Practical aspects of the simulation, such as the choice of grid size, step interval and growth and diffusion rates are described by Hargrove (2000).

The effect of bait clumping on expected levels of control

In an experiment carried out at Rekomitjie Research Station, Zimbabwe the number (C) of tsetse which could be caught using the odour of cattle in a ventilated pit/shed changes as a power function of the mass (M) of animals in the herd (Hargrove *et al.*, 1995). For female *G. pallidipes* the estimated function was:

$$C \approx 4 M^{0.475} \quad (3)$$

The probability (p_M) that a given fly in 1 km^2 around the herd visits that herd on a particular day is simply C multiplied by a constant. For a single host animal weighing 0.4 the probability is *c.* 2% of the population (Torr, in preparation). Thus:

$$\begin{aligned} p_M &= 0.02 (M^{0.475}) / (0.4^{0.475}) \\ &\approx 0.03 (M^{0.475}) \end{aligned} \quad (4)$$

Table 1 shows the estimated percentages for herd of different sizes. The probability (q_x) that a fly does *not* find the herd is $1 - p_M$. If there are n such herds (assumed to be acting independently) in the area, the probability (Q_g) that the fly visits none of them is q_M^n ; the probability (P_g) that it contacts at least one herd is then $P_g = 1 - Q_g$.

Herd size	Mass	Number of herds						
		1	2	5	10	20	40	75
1	0.4	0.020	0.040	0.096	0.183	0.332	0.554	0.780
5	2	0.043	0.084	0.197	0.355	0.584	0.827	0.963
10	4	0.060	0.116	0.265	0.460	0.708	0.915	-
20	8	0.083	0.159	0.352	0.580	0.823	-	-
40	16	0.115	0.217	0.458	-	-	-	-
75	30	0.155	0.287	-	-	-	-	-
150	60	0.216	0.386	-	-	-	-	-
200	80	0.248	0.434	-	-	-	-	-
300	120	0.300	-	-	-	-	-	-

Table 1 The effect of changing herd size, and number of herds per sq km, on the probability that a tsetse fly will visit that herd on a given day.

The probabilities for different numbers of identically sized herds (Table 1) demonstrate the advantage, from the point of view of tsetse control, of having treated animals in a large number of small herds rather than a small number of large herds. The data in Table 1 suggests a probability of *c.* 0.22 that a female *G. pallidipes* in the block should visit a herd of 150 cattle on any given day, given that the herd is present in any 1 km^2 block. The probability that a fly in block i,j is treated on any given day is the product of P_g and $h_{i,j}$.

We also allow the possibility that targets might be deployed in the area. If s targets per sq km are deployed and a fly finds a target on a given day with probability p_t , and if we set $q_t = 1 - p_t$, then the probability (Q_t) that a fly avoids all s targets in a day is $Q_t = q_t^s$. Finally, the probability (P_n) that the fly finds at least one of the treated cattle, or a target, is given by:

$$P_n = 1 - (Q_g (1 - h_{i,j}) Q_t) \quad (5)$$

The modified growth rates and carrying capacities consequent on having the combination of insecticide-treated cattle and targets is given by:

$$r^* = r(1 - \delta_t/r) \text{ and } K^* = K(1 - \delta_t/r) \quad (6)$$

where the imposed death rate (δ_t) can be identified with the probability (P_n) that a fly contacts a treated animal or a target.

Targets

The possibility was allowed that targets might be deployed as an alternative, or additional, means of tsetse control. If s targets km^{-2} are deployed and a fly finds a target on a given day with probability p_t and if we set $q_t = 1 - p_t$ then the probability (Q_t) that a fly avoids all s targets in a day is $Q_t = q_t^s$. Finally, the probability (P_n) that the fly finds at least one of the treated cattle, or a target, is given by:

$$P_n = 1 - Q_g Q_z Q_t \quad (7)$$

Outputs

Herding practices at Mkwaja Ranch

Between 1989 and 1999, the population of Zebu Boran cattle at Mkwaja varied between ~6000 and ~14000 animals. At night the cattle were kept in bomas, with each boma holding between ~150 and ~1700 animals. For grazing purposes, the animals from each boma were divided into herds of 150 animals and these herds grazed separately between 0700 h and 1800 h to the limits of the ranch. While recognising that a few dense thickets prevented cattle from grazing some areas (Fig. 1), the ranch management aimed to produce an even coverage of herds across the ranch. Random herd surveys, herd tracking, and interviews with herders suggested that herds were generally following management instructions. In particular, herds did not: penetrate the dense thickets, range far beyond the limits of the ranch and/or >4 km from their home boma (Fig. 2).

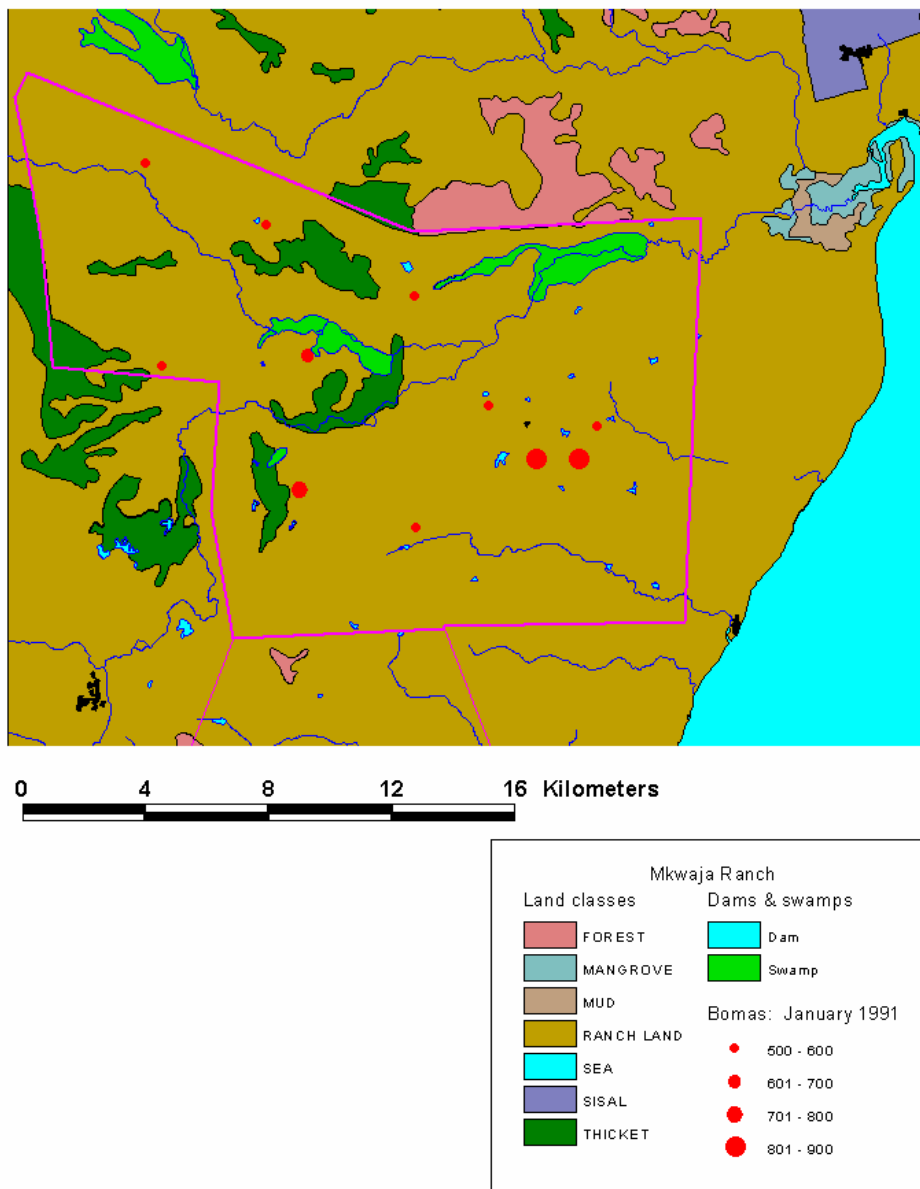


Fig. 1. Map of Mkwaja ranch showing ranch boundaries (solid red line) and location of cattle bomas (red circles; relative size indicates number of cattle per boma) and areas of swamp (light green), thicket (dark green), forest (pink), sisal estate (purple) and water (blue).

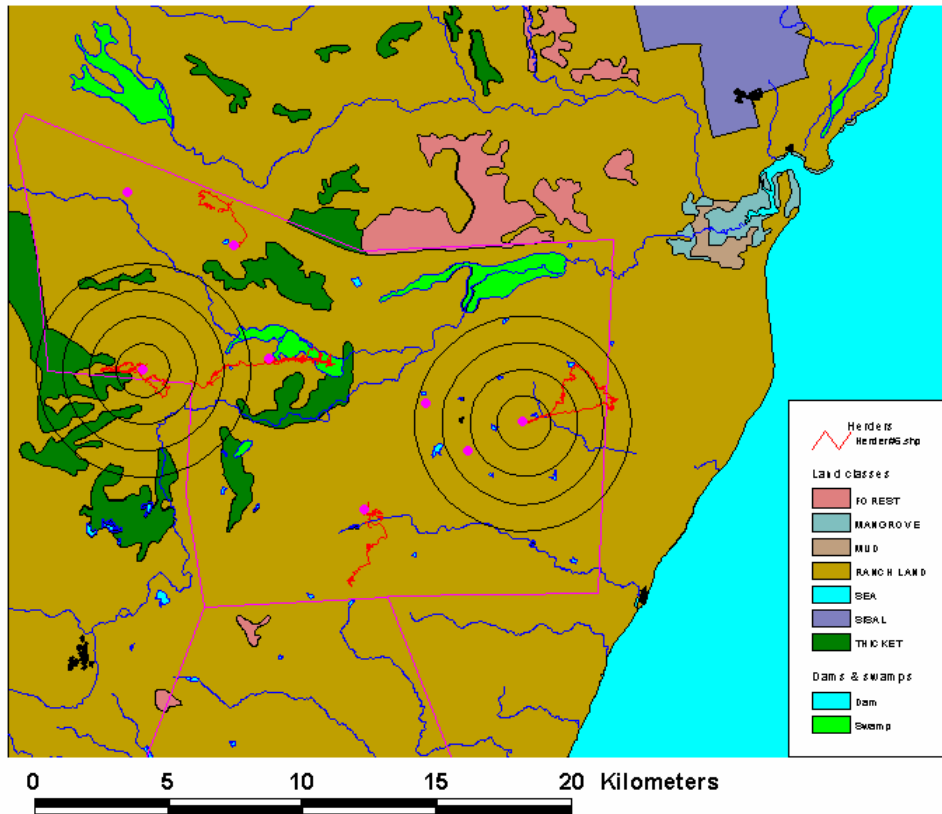


Fig. 2. Bomas (solid purple circles) and tracks (red lines) of herds grazing within Mkwaja ranch in June 1999. Concentric rings at 1 km intervals are shown around two bomas to indicate the grazing ranges of herds. Tracks illustrate how herds remained with ranch generally remained largely within ranch boundary, did not enter thickets and did not travel >4 km from their night bomas. By June 1999, the herd at Mkwaja had declined to <7000 animals and thus only 8 bomas were in use compared to 11 in 1991 (Fig. 1).

For each year we estimated the distribution of cattle by assuming that for each boma, the number of herds was the mean monthly number of cattle recorded at that boma. It was further assumed that cattle did not penetrate thickets or range beyond the ranch boundaries. Otherwise, herds had equal probability of being located anywhere within 4 km of their night boma. For bomas unaffected by ranch boundaries and thickets, the grazing area was assumed to be a circle of $\sim 50 \text{ km}^2$ centred on the boma. The GIS data for Mkwaja were converted into a grid of 1 km^2 cells and these data were then exported as an ASCII file which could then be imported into the EXCEL simulation model.

To estimate the probability of a particular cell containing a herd we used the following approach. Consider a boma containing n herds which graze over an area of g cells, where each cell is 1 km^2 . For one herd from the boma, the probability of one of the g cells containing that herd is $1/g$ and thus the probability of a cell not containing a herd is $1-(1/g)$. It follows from this that the probability of a cell not containing any herds is $(1-(1/g))^n$ and thus the probability (p) of containing at least one herd is:

$$p = 1-(1-(1/g))^n$$

The grazing ranges of several bomas overlapped. For cells within the grazing range of, say, bomas a and b the respective probabilities of them containing a herd from a or b are p_a and p_b . Thus the probability of the cell not containing a herd from bomas a or b is $(1-p_a)$ and $(1-p_b)$. The product of these is the probability of not containing a herd from either boma

and thus the probability (h) of the cell containing at least one herd from one of these bomas is:-

$$h = 1 - (1-p_a)(1-p_b)$$

The same approach can be generalised for a cell within the range of any number of bomas.

Figure 3 shows the estimated distribution of (insecticide-treated) cattle on Mkwaja Ranch during 1991 using the above approach. Figure 4 shows the tsetse population levels after a year of control using this cattle distribution. In the example shown it was assumed that a female *G. pallidipes* had a daily probability of 0.22 of contacting a herd in a 1 km² cell. Other input parameters are given in the legend of the figure. As a simple measure of the differences between the effects on the tsetse population of different treatments the geometric mean of the tsetse population was calculated over a portion of *c* 90% of the ranch.

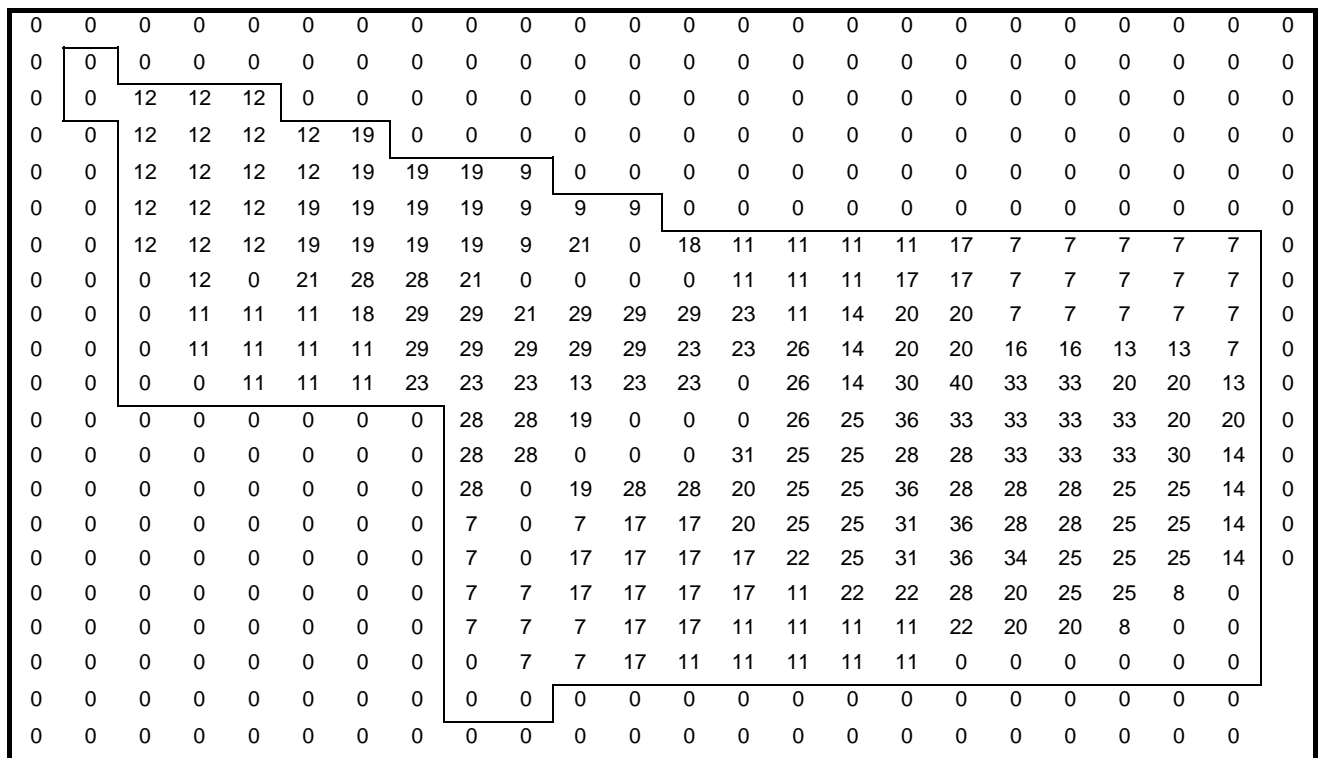


Figure 3 The estimated distribution of cattle herds on Mkwaja Ranch, Tanzania in 1991. The solid line in the interior of the figure shows the boundary of the ranch. Each cell denotes 1 km² and the number in that cell is the estimated percentage probability that a herd of 150 cattle will graze in that area on any particular day. The blank cells at the bottom right of the figure denote the coastline of the Indian Ocean at the south-east extremity of the ranch.

92	89	85	83	82	82	83	84	86	87	89	90	91	92	93	93	94	94	95	95	96	96	97	97
88	83	76	72	71	72	73	76	78	81	83	85	87	88	89	90	91	92	92	93	93	94	95	95
85	76	62	55	53	57	60	64	68	72	75	79	81	83	84	85	86	87	88	89	90	91	92	93
82	71	54	45	41	40	40	48	53	59	65	69	73	75	77	78	80	81	82	84	85	86	88	89
80	68	50	39	33	29	27	29	34	42	51	57	61	64	67	68	70	71	73	75	77	79	81	83
79	67	48	37	29	22	19	20	23	30	36	41	47	51	53	54	56	57	61	64	67	70	73	76
80	68	50	37	28	20	16	14	16	21	24	30	30	33	35	36	37	38	43	48	51	56	61	68
81	71	57	41	32	20	14	11	12	16	18	21	22	22	23	23	23	25	31	36	40	46	53	62
83	75	62	45	34	24	16	11	9	10	10	11	11	12	14	14	14	16	21	26	31	37	46	58
86	78	67	51	39	29	21	13	9	7	7	7	7	8	8	8	8	10	13	16	22	29	40	55
88	82	74	62	48	38	29	19	12	8	8	7	6	7	5	5	5	5	7	9	14	22	34	52
90	86	80	71	62	52	42	30	16	11	9	9	8	6	4	3	3	3	4	6	10	18	30	50
92	89	84	78	71	62	52	38	21	15	13	11	8	5	3	3	2	2	3	5	8	15	29	49
94	91	88	83	77	70	60	47	29	24	16	10	7	5	4	3	2	3	3	5	9	16	30	50
95	93	91	87	82	75	67	55	40	31	21	14	10	7	5	4	4	4	5	7	11	18	31	51
96	95	93	90	86	80	72	61	47	37	25	17	13	11	9	8	7	7	8	10	15	22	35	52
97	96	94	92	89	84	77	67	53	41	30	22	19	17	16	14	13	13	15	18	23	33	41	
98	97	96	94	91	87	81	73	60	49	40	31	27	26	26	25	25	25	27	31	38	47	52	
98	98	97	95	93	90	85	79	70	59	51	43	41	40	39	39	41	45	48	52	56	61	64	
99	98	97	96	95	92	89	85	79	73	67	63	60	59	58	59	60	62	64	67	70	72	74	
99	99	98	97	96	94	92	89	86	82	79	76	74	73	72	72	73	75	76	78	79	81	82	

Figure 4 The predicted distribution of tsetse flies on Mkwaja Ranch, Tanzania in 1991. The number in each cell is the estimated percentage of the holding capacity remaining after a year's control using insecticide-treated cattle, except that the double lines in the interior demarcate the regions over which the geometric mean of the tsetse population was calculated (see text). Other boundaries and information as in Fig. 1. Input parameters: $\alpha = 0.08$; $\delta = 0.21$; $r = 0.15$.

The model predicts that a tsetse population, with a natural growth rate of 1.5% per day, the 1999 tsetse population should fall to a new equilibrium level of *c.* 10% (Fig. 5). In other years the numbers and distribution of cattle were such that the decline in population was not as great. In 1989 and 1990, for instance, the new equilibrium was closer to 15%. This latter level of reduction is consistent with the data of Fox *et al.* (1993; their Table III) on the rate and extent of the decline in the *G. pallidipes* population (Fig. 6). It was also consistent with their observations of a substantial reduction in fly numbers and trypanosomiasis and a significant improvement in herd health. The level of control does, however, fall far short of eradication, consistent with the continuing tsetse problems experienced to this day by the ranch management (Hargrove *et al.*, 2000). While there clearly has been a detrimental effect of declining numbers of treated cattle on the ranch, the graph suggests that the changing cattle population between 1989 and 1999 does not have a *major* impact on the levels of suppression; or, at least, not if the estimate cattle distributions accurately reflect the true situation.

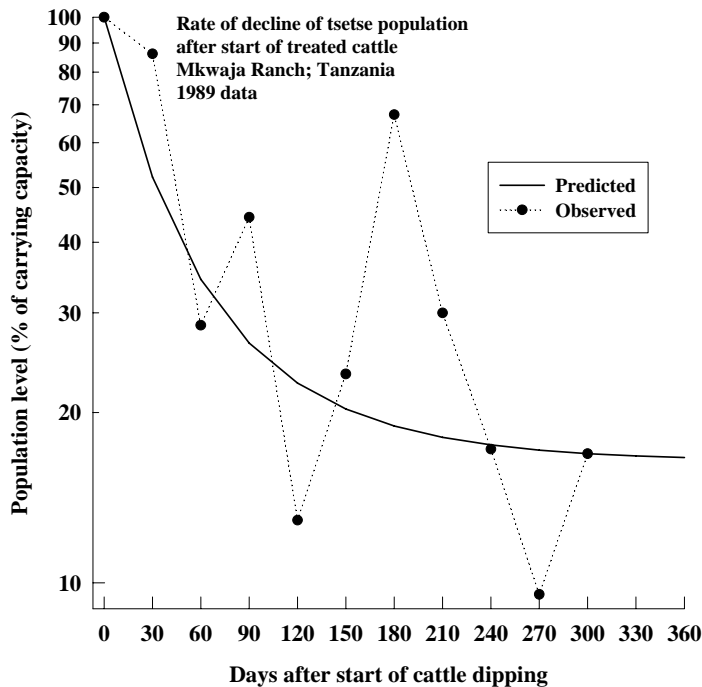


Figure 5 Observed and predicted rates of decline of the population of *G. pallidipes* following the introduction of insecticide-treated cattle in 1989. Mkwaja Ranch, Tanzania.

If the supposed levels of treatment were actually lower than 22% per day, then the effect on the tsetse population would, of course, be smaller. However, even if the treatment levels were actually half of the figure supposed the resulting level of control would still be *c.* 80%. Since one is really only interested in order-of-magnitude changes in control levels we may be confident that any errors made in the selection of the value of δ in the above modelling procedure will not seriously affect the conclusions drawn.

The predicted changes in tsetse populations are dependent on the assumed diffusion coefficient, emphasising the importance of re-invasion. Again, however, as long as the true value of this parameter is not greatly different from a value of 0.04 the predicted level of control is always of the order of 90% (Fig. 7). It is only for flies which move very slowly where we might expect a significantly better result. In this regard it is interesting that *G. m. morsitans*, which is assumed to be less mobile than *G. pallidipes* seems to have largely disappeared from Mkwaja since the introduction of insecticide-treated cattle.

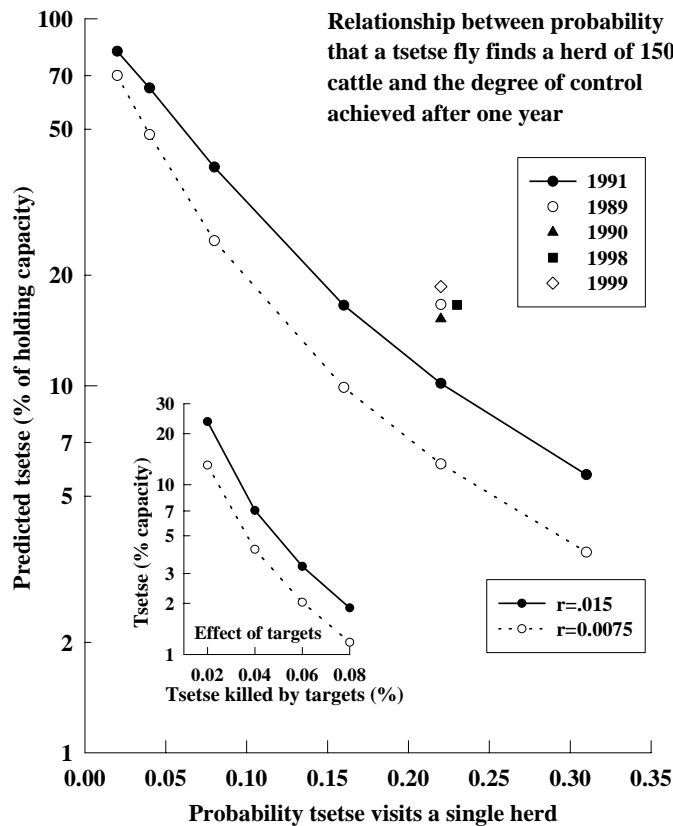


Figure 6 The relationship between the probability that a female tsetse fly finds a herd of cattle in a 1km² of country on a given day and the resulting decline in the fly population in a year. The results for two different levels of the fly's natural growth rate (r) are shown. *Inset* The predicted effect on the tsetse population of deploying 1, 2, 3 or 4 odour-baited insecticide treated targets in each km² of the ranch.

The other parameter which affects the level of control is, of course, δ - the proportion of flies killed each day by the insecticide-treated cattle. We now consider what would have happened if the herds had kept using the same pastures – but were split into smaller units. For instance, suppose that the herd size was 75 instead of 150, and that this resulted in a doubling of the probability that there was a herd in any sq km on any given day. The smaller herd attracts 15.5% of the population in the square, compared to 22% for the herd of 150 animals; but since there are two such herds, assumed to be acting independently, the total percentage attracted is 31%. Table 1 shows that this is the same percentage as is predicted would be attracted by a single herd of 300 animals.

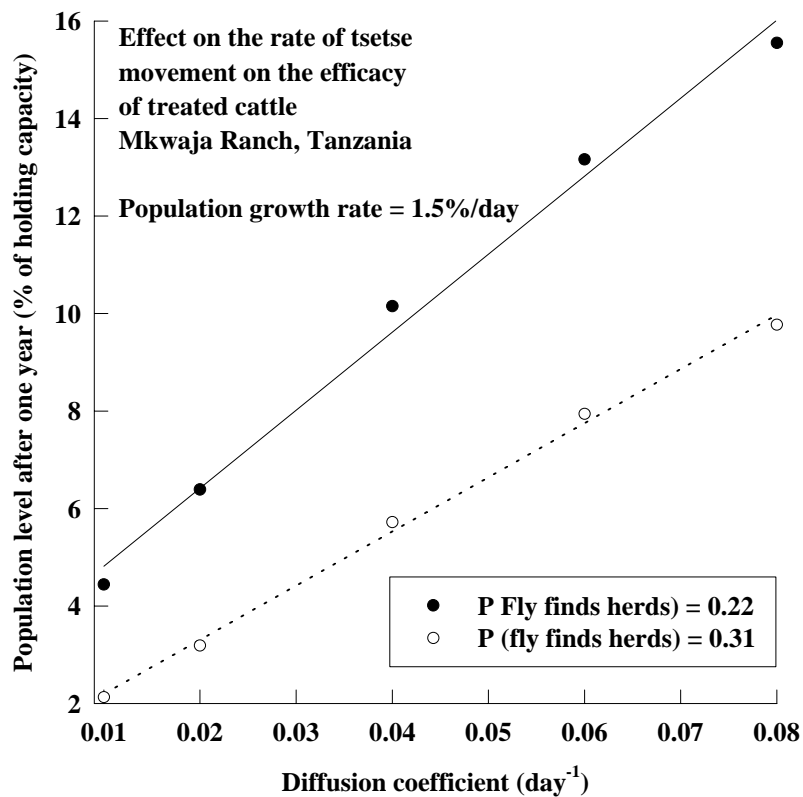


Figure 7 The effect of the rate of tsetse movement on the efficacy of insecticide-treated cattle as agents of tsetse control on Mkwaja Ranch, Tanzania.

The model predicts that this change in herding pattern would result in a further halving of the post-treatment equilibrium tsetse population (Fig. 7). Further reductions could be effected if odour-baited target were deployed on the ranch – either in the areas of the ranch which are not used by the cattle for grazing, or simply on the borders of the ranch acting as a partial barrier to re-invasion (Fig. 8).

A combination of smaller herd size and a judicious use of targets might thus have been used on Mkwaja to reduce the tsetse population to 1% of its original carrying capacity. This level of control would probably have allowed the management to stop using Samorin® as a prophylactic against trypanosomiasis - but it would not have removed the trypanosomiasis problem entirely. Similar levels of control would have been achieved if odour-baited targets had been used, within the ranch boundaries only, at a density of 4 km⁻² (Fig. 8).

Study of the details of the tsetse population distributions on and around shows that, for all of the runs of the model, numbers increased rapidly once one moved away from the ranch boundary. This implies that there is strong re-invasion pressure. It may be concluded,

therefore, that not control operation which is restricted to the area of the ranch alone will provide satisfactory relief from trypanosomiasis.

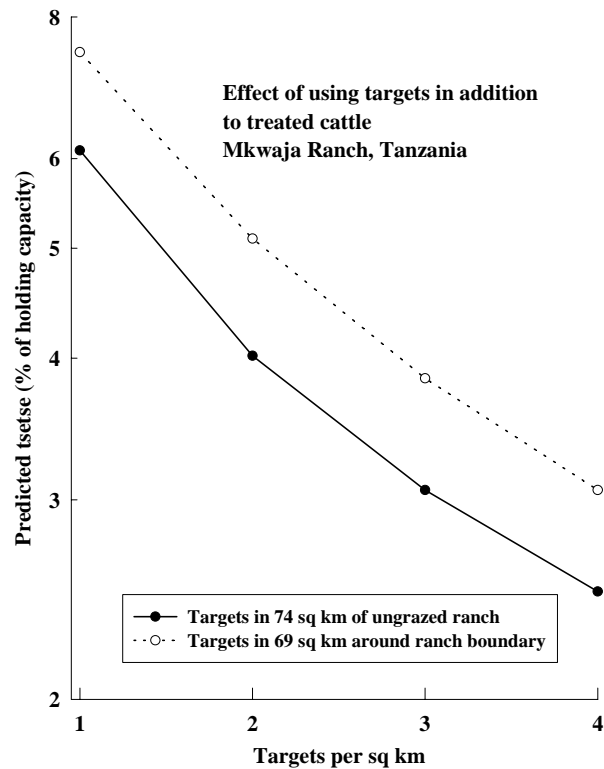


Fig. 8 The predicted effect of using odour-baited targets in addition to insecticide-treated cattle as a means of tsetse control on Mkwaja Ranch, Tanzania. The targets were supposed to be placed either within the ranch in areas not grazed by the cattle, or in a 1 km band around the ranch boundary.

Even quite a modest effort just outside the borders of the ranch would, however, result in a marked improvement in the situation. Thus, if targets were deployed throughout the ranch, and in a barrier of depth 3 km outside the ranch, the model predicts that the tsetse population would be reduced to 0.03% of its holding capacity. To give this figure some meaning in terms of actual fly numbers this means that if the original tsetse density had been $60,000 \text{ km}^{-2}$ the target operation would have reduced it to just 20 within six months.

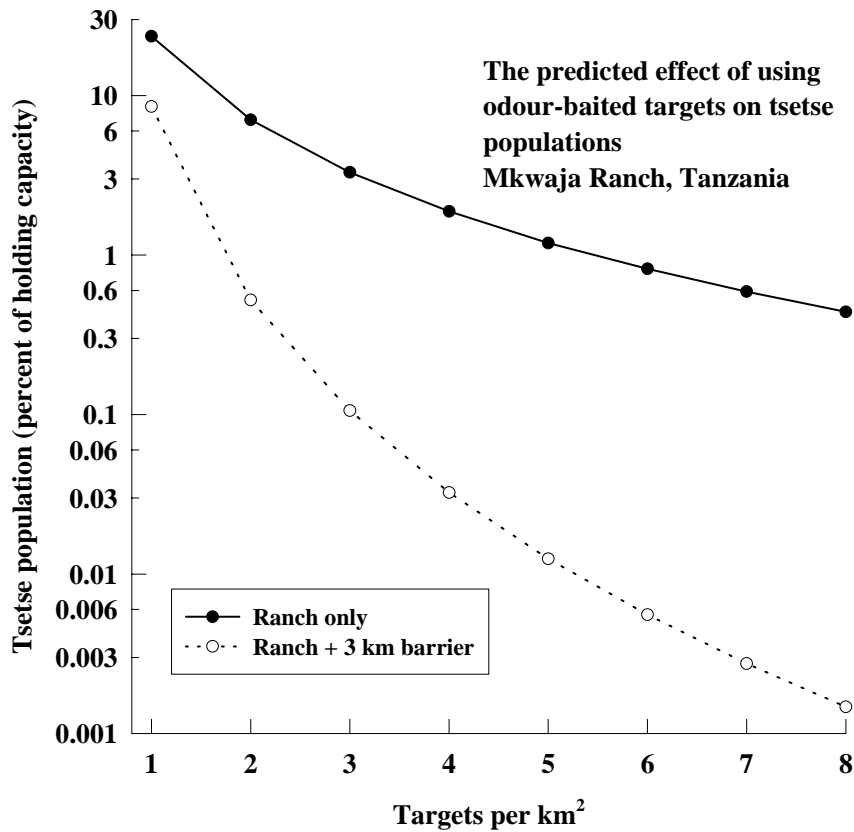


Figure 9. The predicted effect of using odour-baited targets instead of insecticide-treated cattle as a means of tsetse control on Mkwaja Ranch, Tanzania. The targets were supposed to be placed either within the ranch only, or also in a 3 km band outside the ranch boundary.

Discussion

The simulations carried out in this study provide good descriptions of what actually happened in the experimental use of insecticide-treated cattle in Tanzania. As such it appears that the model developed is a useful tool for predicting the outcome of tsetse control operations.

It is worth recording at this stage, a summary of the advice given by Vale in an unpublished report arising from a visit he made to Mkwaja Ranch in June 1989. Vale's "Suggestions for General Strategy" are given in point form below since they contain much of the advice required for any operation involving the use of baits.

- The technology is still experimental and unpredictable so no plan for control can cover more than six months. Moreover, the idea of bait systems of control is that the work should become more economical and effective operation as it proceeds.

- Tsetse should be removed from the ranch and small-farming settlements nearby and, eventually to prevent re-invasions, from adjacent areas where there is no settlement and where tsetse abound. These aspects will differ in the extent to which they rely on the use of treated cattle as against artificial baits.
- Where cattle occur in large numbers and are anyway being dipped against ticks it makes sense to use an acaricide which also kills tsetse.
- The cattle should be grazed close to the tsetse habitat. If large herds of cattle are kept in extensive grassland only 5-10% of tsetse feeds might come off cattle. The percentage might well rise to 75% if the larger numbers of smaller herds were kept in tsetse habitat and the flies would decline more.
- If this strategy is not economical the herds should be grazed near the tsetse habitat during the times when tsetse are most active.
- If populations of tsetse persisting in ungrazed thickets targets could be deployed in paths through the thickets. Targets could also be deployed later on the ranch boundaries to reduce re-invasion.
- Monitoring of fly and disease levels is important in order to assess challenge, and the effects of the baits in and around the treatment area.
- Because the approach is still experimental it is important that entomological investigations are carried out as part of the control procedure. Tests of traps and odours, and studies of tsetse habitat preferences and activity patterns are obvious areas which require investigation.
- The importance of an interactive approach to the control programme was emphasised.

One concludes simply that the outcome of the Tanzania trials and the simulations of them carried out here strongly support Vale's views on the matter. Experience has shown that, properly managed and appropriately applied, insecticide-treated cattle and odour-baited targets are powerful weapons in the arsenal of tsetse control weapons. But, as with all such weapons, their indiscriminate use, without due regard to potential levels of re-invasion and without an interactive approach, will often be disastrous both from a veterinary and from an economic point of view.

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Insecticide-treated cattle for tsetse control in Tanzania: 3. Proposed operations in Tanga Region.

SUMMARY

Studies were undertaken to assess the suitability and acceptability of using insecticide-treated cattle or other community-based methods of controlling trypanosomiasis at two sites in the Tanga Region of Tanzania. For both areas, participatory mapping techniques were used to obtain information on the extent to which herds of cattle moved from their home village as they grazed. In Handeni, cattle were predominantly owned by Maasai pastoralists who grazed traditional zebu cattle over distances of 3 – 8 km according to season. In Tanga, on the other hand, cattle were a mixture of crossbred Zebu-Friesian animals kept for dairy production and traditional grazed zebu animals. Grazing ranges were small, partly because many cattle were kept under a zero-grazing regime and because grazing and water were locally abundant.

A simulation model was used to predict the effect of using of insecticide-treated cattle and/or odour-baited targets as methods of tsetse control in the study areas. Functions were developed which could be used to estimate the probability that a fly contacts a herd or a target on any given day. For both districts it was necessary to make assumptions about the likely grazing patterns of the livestock and the predictions of the time course of control will only be as good as these assumptions.

In Handeni, the use of insecticide-treated cattle should allow better than 99% control within ~3-8 km of the villages with substantial numbers of cattle. The extent of control varying according to assumptions regarding the grazing range of insecticide-treated cattle and their impact on tsetse populations. Predicted tsetse numbers increased rapidly beyond the range of the grazing area. Changes to the assumed natural growth and movement rates of tsetse, similarly, had modest effects on the predicted levels of control. The deployment of a ring barrier of only *c.* 1600 targets around the major cattle centres could give rise to an area of an area > 1000 km² virtually free of tsetse. Insecticide-treated cattle would be less successful in Tanga where the predicted fly-free area around the villages is much smaller. A barrier involving the use of 1000 targets at 4 km⁻², could be used to reduce the tsetse population within <10% of the carrying capacity in 90% of the cells within the barrier.

The findings of the project were presented at meetings with livestock owners and other stakeholders in Handeni and Pangani. The research findings and the outcome of the stakeholder meetings have provided the basis of a proposal for an EU-funded project to control tsetse in Tanga Region.

Activities

Cattle ownership, distribution and management

The study focussed on cattle owners in two areas in Tanga region: an area of ~2000 km² in Handeni District and an area of 500 km² on the Tanga coast, comprising parts of Pangani, Muhesa and Tanga Districts. The field work was undertaken between June and September 1999.

Cattle numbers and herd compositions.- The numbers of cattle within the study areas were estimated from a number of sources. In Handeni, group meetings were arranged with Maasai and Zeguwa livestock owners from the villages and hamlets lying within and bordering the Lengusero area. At the meetings, livestock owners provided estimates of the number and composition of cattle they owned and provided details of other cattle owners in the villages who were not at the meetings. During subsequent surveys of boma locations and herd grazing areas it was possible to cross-check a sample of these herd estimates.

In Tanga, the TDDP project marked the positions of all the cattle owners in the study area using a geographical positioning system (GPS) and recorded all cattle herd sizes.

Cattle distribution.- At the group meetings with owners of grazed cattle, participatory mapping techniques were used to explore the grazing patterns of cattle. Maps of the area were drawn and identifying features and homestead positions were marked. Grazing areas and watering points were indicated and seasonal differences in use and the distances travelled were discussed.

Following these meetings, surveys were conducted to determine whether herds were indeed grazing in the areas indicated by the owners. During these surveys, the different grazing areas were visited and the positions of any herds that they found were recorded using a GPS.

Location of kraals.- During the surveys and village meetings, the locations of a sample of individual kraals were recorded using a GPS.

Cost-effectiveness, acceptability and sustainability of insecticide-treated cattle

The potential acceptability of various tsetse control options was also investigated through interviews with farmers in both Handeni and Tanga districts. These issues were explored indirectly, through examining the role and importance of cattle in the farming system. More directly, cattle constraints, and in particular the importance of trypanosomiasis as a constraint, were examined. Information was collected on current tsetse and tick control measures used and the costs of control. The interviews also sought to determine the suitability and acceptability of other potential solutions for controlling the disease..

Tsetse and trypanosomiasis surveys.- Tsetse traps were set in both study areas in June 1999 to provide objective evidence of fly numbers. Bloodmeals from flies caught in traps were analysed by ICIPE.

Analysis of spatial data

Tanga data set.

The available cattle distribution data were as follows: i) Total numbers of cattle per sq. km ii) Numbers of herds km⁻². iii) Numbers of cattle per herd (*i. e.* ratio of first two data sets). The situation differed from Handeni in that in Tanga there were both ‘zero-graze’ cattle which remained continuously in their bomas and free-range grazing animals which grazed within 3 km of their bomas.

Grazing herds

For the grazing cattle, a very simple approach is to assume that the herds in each cell spend equal times grazing in their own, and in adjacent, cells. One could thus form a new distribution for total cattle where, for example, the number ($n_{i,j}$) in each cell is taken as the average of the 9 cells (3x3) in the immediate neighbourhood. Thus:

$$n_{i,j}^* = \frac{1}{9} \sum_{r=i-1}^{r=i+1} \sum_{c=j-1}^{c=j+1} n_{i,j} \quad (1)$$

The same thing can then be done with the numbers of herds in each cell and the resulting data can then be used, as above and as shown previously, to estimate the probability that a fly in cell i,j contacts at least one host animal on a given day. This approach has been used, and has been compared with the more sophisticated approach described below.

In the latter approach we define $p_{i,j}^*$ as the probability that, on a given day, a fly in square i,j contacts at least one of the cattle defined in the data set as resident in that square. Similarly we define $q_{i,j}^* = 1 - p_{i,j}^*$ as the probability that it fails to contact any of these cattle. One needs to make allowance for the fact, however, that cattle from neighbouring squares may graze in i,j and that the fly might also contact one of these cattle. The probability that this happens clearly declines with the distance between i,j and the home cell (r,c , say) of the foreign herd, and we accordingly define a ‘dilution factor’ $d_{i-r,j-c}$ and assume that, on a given day, a tsetse fly in i,j contacts a herd based in r,c with probability $p_{i,j}^* / d_{i-r,j-c}$. As before the probability that the fly did not contact the foreign herd is $1 - (p_{i,j}^* / d_{i-r,j-c})$.

In principle one could take into account the probability that a fly in i,j is captured by herds based in any other cell but, in practice, this is too cumbersome. Moreover, the probabilities for all distant cells are so small that they may safely be ignored. In this study r and c were allowed to vary between -3 and $+3$ so that the killing effects of the herds only in i,j and the 48 cells (*i.e.* 48 km²) closest to it were taken into account. The effects of all more distant herds were ignored.

Assuming independence of action of the herds in each cell, the probability ($q_{i,j}$) that a fly contacts none of the cattle in the 49 cells of interest is given by the product of probabilities for each cell. The probability therefore, that it contacts at least one animal is the complement of $q_{i,j}$. Thus:

$$p_{i,j} = 1 - q_{i,j}$$

$$= 1 - \left[\prod_{r=i-R}^{r=i+R} \prod_{c=j-C}^{c=j+C} 1 - \left(\frac{p_{r,c}^*}{d_{i-r,j-c}} \right) \right] \quad (2)$$

The $d_{r,c}$ should be chosen such that they reflect a reasonable decline with distance in the probability that a foreign herd grazes in i,j , although the precise nature of this decline is not clear and will vary in different situations. For the present study an inverse-square relationship was assumed.

Zero-grazing herds

For the zero-grazers the situation is much simpler because we only have to consider the home cells for each herd. The capture probabilities are therefore estimated in the normal fashion using equation (3) above. We define $Q_{i,j}^z$ as the probability that a fly in cell i,j fails to contact a zero-grazing animal in that cell on any particular day.

Handeni data set

The Handeni data were provided in the form of the numbers of herds per km² based in each of 15 villages, the total numbers of cattle in those villages, and the approximate extent to which the herds from each village moved while they were grazing. The expected changes consequent on the use of insecticide-treated cattle were modelled using EXCEL. Each village was assigned a worksheet of a workbook on which a map of the area was divided into square cells of side 1-km. The square on row i and column j of the sheet for village k is referred to below as cell i,j,k .

As with earlier studies it was necessary to estimate the probability that a fly contacts a herd on any given day. To this end, assumptions needed to be made about the relationship between the distance of each square on a sheet from the corresponding village and the expected number of herds of cattle to be found in that cell on any given day. Two scenarios were modelled. In the 'optimistic' case it was assumed that herds ranged up to 8 km from their boma and had an effect on tsetse populations with all the cells through which they passed. In the 'pessimistic' scenario, it was assumed that herds only had an effect on cells containing bomas, and cells adjacent to this.

Optimistic scenario.-All squares which were within d km (where $d \leq 8$ km) of the village were assigned a value of $m_{i,j,k} = 1 - ((d_{i,j,k} - 1)/10)$. This "density factor" thus decline linearly from 1 to 0.3 as the distance from the village increased from 0 to 8 km. For $d > 8$ km, $m_{i,j,k}$ was assigned a value of zero. It was then assumed that the probability ($s_{i,j,k}$) of finding a given herd from village k in square i,j was given by:

$$s_{i,j,k} = m_{i,j,k}^B \quad (3)$$

where B is a parameter which can be chosen such that the predicted cattle distribution matches the grazing pattern observed in the field. The way in which the choice of B affects the grazing distribution is shown in Fig. 4. In the first instance, and in the absence of more detailed information on the exact movements of cattle, values for B of 2 - 4 were chosen for the present simulations.

In the present case, if there are H_k herds in village k , the expected number ($h_{i,j,k}$) of those herds to be found in square i,j,k is given by:

$$h_{i,j,k} = s_{i,j,k} H_k \quad (4)$$

In order to estimate the probability that a fly contacts such a herd of cattle, on any given day, we again use the results of an experiment carried out at Rekomitjie Research Station, Zimbabwe. Using equation (4), the probability (p_k^*) that a fly is captured by one such herd on a given day is:

$$p_k^* \approx 0.03 (M_k^{0.475}) \quad (5)$$

where $M_k = c_k/H_k$ is the mean mass of animals in a herd from village k ; c_k is the total number of cattle in that village.

The probability (q_k^*) that a fly evades capture by this herd is $1 - p_k^*$. The probability ($q_{i,j,k}$) that a fly in cell i,j is not captured by *any* of the herds from village k is $q_{i,j,k} = (q_k^*)^N$ where, for ease of notation and presentation, $h_{i,j,k}$ been redefined as N .

The present simulations are complicated by the fact that the grazing areas of the various villages overlap. A fly in a given cell i,j could thus contact herds from more than one village. In general, the probability ($p_{i,j}$) that it is captured by any herd, from any village, is:

$$p_{i,j} = 1 - \prod_{k=1}^{15} q_{i,j,k} \quad (6)$$

The $p_{i,j}$ were used as the basic input data frequency for the simulation procedure. It was recognised, however, that the overall level of this parameter was somewhat uncertain – because of the paucity of data on the actual numbers of herds present in various part of the grazing area on any particular day. The imposed death rate (δ) was accordingly defined as:

$$\delta = A \cdot p_{i,j} \quad (7)$$

where A is a constant used to adjust the overall level of δ . An example of the resulting matrix of estimated capture probabilities is shown in Figure 5.

Pessimistic scenario.- In this case, we assumed that herds did not range greatly from their bomas and adopted the same approach used for cattle in Pangani district. That is, the herds only had an effect on 9 cells these being a cell containing a boma plus those cells adjacent to it.

Targets

The possibility was allowed, for both study areas, that targets might be deployed as an alternative, or additional, means of tsetse control. If s targets km^{-2} are deployed and a fly finds a target on a given day with probability p_t and if we set $q_t = 1 - p_t$ then the probability (Q_t) that a fly avoids all s targets in a day is $Q_t = q_t^s$. Finally, the probability (P_n) that the fly finds at least one of the treated cattle, or a target, is given by:

$$P_n = 1 - Q_g Q_z Q_t \quad (8)$$

The various spatial data, (e.g. positions of herds, kraals, villages, vegetation types) were incorporated into Geographical Information System (GIS) using the software package Arcview (ESRI, Aylesbury, UK) for analysis. The study area was divided into a grid of 1 km^2 cells and the probabilities of finding a herd in any given cell.

Changes in tsetse populations were modelled using the Fisher equation which defines the *instantaneous* changes in population density $\rho(\mathbf{x}, t)$ at any point \mathbf{x} and at any time $t \geq 0$, for a population with predefined carrying capacity K and rates of growth r and movement α (Williams *et al.*, 1992; Hargrove, 1998; Hargrove, 1999). If an additional mortality rate (δ) is imposed on the population then the growth rate and carrying capacity become $r^* = r(1 - \delta/r)$ and $K^* = K(1 - \delta/r)$ respectively; the Fisher equation applies as before with r^* substituted for r and K^* substituted for K .

The model assumes that tsetse populations move by diffusion and grow logistically. The population changes occurring over small *finite* time steps are modelled using Excel spreadsheets with programmes written in Visual basic. The procedure is described full by Hargrove (1998, 1999). In most cases pre-control tsetse population levels were assumed to have an arbitrary carrying capacity of 100 units in each cell. Distributions of insecticide-treated cattle and/or odour-baited targets were used to estimate the value of δ in each case.

Outputs

Handeni District

In Handeni district, the study area comprised an area of ~2000 km² (Fig. 5). The area comprises Lengusero and some eight Maasai and Ziguwa villages that surround it. Lengusero itself is largely unpopulated but the local Maasai community holds the title deed for it and ultimately they plan to move there from the surrounding villages.

Handeni project area

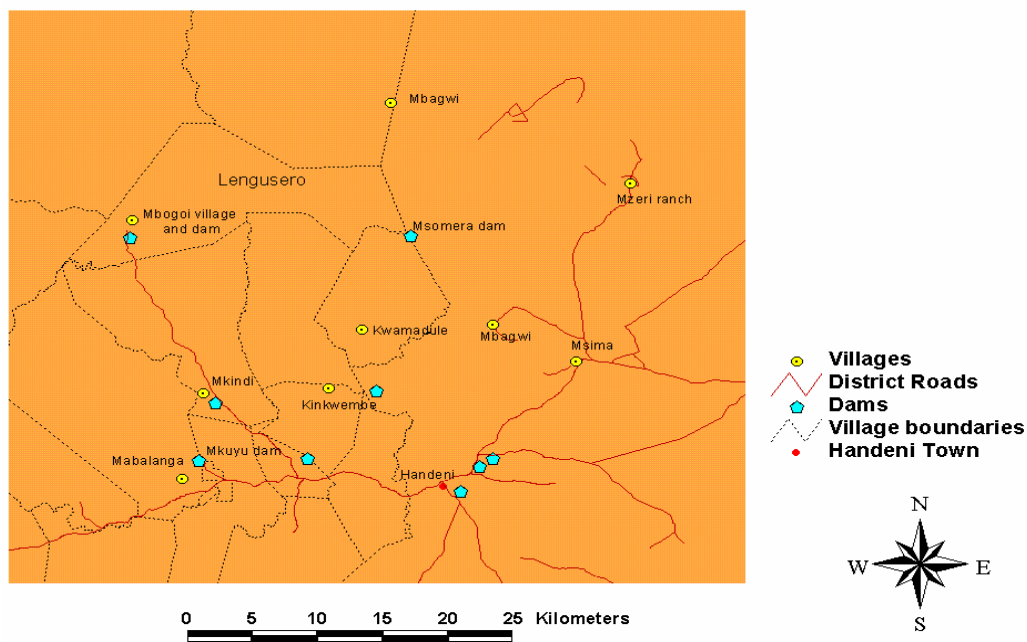


Fig. 5. Handeni project area showing location of villages, dams and main roads.

Assessing the importance of trypanosomiasis

Farmers' perceptions.- In interviews with farmers, animal diseases were judged to be the most significant constraint to livestock production. For instance, 63% of farmer groups ranked diseases as the most important constraint and for the remaining groups, diseases were ranked second or third. Other constraints, in order of importance, were availability of water and feed and the cost of drugs.

The four main diseases in the project area were, in order of importance, East Coast Fever (ECF), Trypanosomiasis, Babesiosis and Anaplasmiasis, (Table 1).

Table 1: Importance rank of cattle diseases (% of farmer groups).

	<i>Rank 1</i>	<i>Rank 2</i>	<i>Rank 3</i>	<i>Rank 4</i>
Trypanosomiasis	25.0%	50%	13%	
Anaplasmosis			38%	38%
Babesiosis		38%	25%	13%
ECF	63%			13%
Helminths			13%	
Other diseases	12	12	11	36

Key: Rank 1 = most important disease, Rank 2 = second most important disease etc.

Farmers ranked ECF as the most important disease because it

- Is acute
- Kills a large number of animals (particularly calves)
- Affects a large number of livestock owners and
- Occurs every year

Trypanosomiasis was ranked the most important disease by farmers Mbogoi and Mkindi and was ranked second most important by 50% of the groups. Almost all groups said that while it does not cause as much mortality as ECF, they considered important because it:

- Is frequent;
- Affects many cattle
- Leaves cattle weak and more susceptible to babesiosis and anaplasmosis
- Affects productivity, causing abortions, low milk production and poor sale prices
- Is expensive to treat because of the frequency of occurrence.

Tsetse and trypanosomiasis surveys.- Results of tsetse and trypanosomiasis surveys conducted in June 1999 provide objective evidence that trypanosomiasis is an acute problem in the area. Odour-baited Epsilon traps set around Mbogoi for 16 trap-days in June 1999 gave a mean catch of 65 tsetse (primarily *G. pallidipes*) per trap/day. Blood samples taken from 44 cattle from 3 different cattle herds from Mbogoi village showed that the mean PCV was 23% and, despite the reportedly recent use of Berenil, 20% of blood samples from cattle were found to have trypanosomes.

There is a large population of wild hosts in the area and the analysis of bloodmeals from flies caught in traps showed that most tsetse had fed on wild game rather than livestock (Table 2).

Table 2. Host sources of tsetse from Handeni

	Number of flies	Percentage (%)
Buffalo, kudu etc.	26	55
Warthogs and wild pigs	14	30
Humans	3	6
Goats	3	6
Cats	1	2

Current trypanosomiasis control measures

Most livestock owners were using only drugs to control trypanosomiasis. Berenil is the most commonly used drug. It was used by all respondents in all the villages surveyed, except in Mabalanga village where 30% of cattle owners use Samorin instead. In most villages, both Novidium and Samorin are used rarely or by very few individuals.

Farmers favoured Berenil because it is effective against babesiosis as well as trypanosomiasis. While the frequency of Berenil use depended on herd health and money to purchase the drugs, most cattle owners reported treating their cattle every 3-4 weeks. If these estimates of treatment frequency are correct, then based on the current Handeni market price of 500/= per sachet of Berenil¹ and treating the whole herd once per month, the annual cost for the average Maasai cattle herd (34 adults) would be 204,000 Tsh compared to 72,000 Tsh for the average Zeguwa herd (12 adults).

Farmers had little knowledge of any tsetse control techniques, including the use of insecticide-treated cattle to control tsetse. No indigenous tsetse control measures were identified; some grazing areas were thought to be worse for tsetse but cattle owners were generally unable to avoid these due to feed shortage problems.

To summarise, trypanosomiasis is clearly an important constraint in Handeni; livestock owners consider it one of their major problems and trap catches confirm that tsetse numbers are high. There is heavy reliance on the frequent use of drugs, particularly Berenil, to control the disease. This is a costly strategy and could lead to drug resistance in the longer term.

Cattle numbers, distribution and density

Herd sizes and compositions.- An average household herd size of 28 cattle was derived from a sample of 145 cattle-owning households. The average composition of the herd was 75% adults and 25% calves. Almost all of the livestock in the project area are indigenous Zebu cattle.

¹ The farmer groups were asked the price of trypanocidal drugs. The prices quoted for Berenil ranged from 400/= to 700/= per sachet, with 500/= to 600/= being mentioned most often

The average Maasai herd size was 45 cattle (34 adults and 11 calves) and the average Zeguwa herd size was 16 cattle (12 adults and 4 calves). From these figures, estimates of total cattle and average cattle per household in each village were calculated (Table 3).

Table 3: Average household cattle herd sizes and compositions and total cattle per village.

Village	Cattle owners	Adult cattle per household	Calves per household	Average cattle per household	Number of cattle owners	Total cattle per hamlet or village
Mbogoi	M	31	9	38	13	845
Kwamadule, Malezi	M	62	16	79	20	2254
Mkindi	M	27	10	38	33	2548
Kikwembe	M	44	10	56	11	774
Mabalanga	M	8	5	13	4	94
Mbagwi	M	-	-	-	60	3634
Mkindi	Z	9	3	12	34	476
Kikwembe	Z	14	5	20	39	849
Mabalanga	Z	15	5	21	17	450
Total					231	11924

Key: Z = Zeguwa, M = Maasai

Cattle distribution.- Information on cattle distribution and movements was collected through participatory mapping of villages and grazing areas. A sample of cattle boma positions, grazing herd positions and other significant features were marked using a GPS. These GPS positions were input into a geographical information system (GIS) of the project area. From these positions and the participatory village maps, estimates of the remaining boma positions were made and input into the GIS. The consequent map of cattle distribution (Fig 6) shows that the cattle distribution in the project area is patchy, with a high concentration of cattle within and around Mkindi, Mabalanga, Kinkwembe and Kwamadule villages.

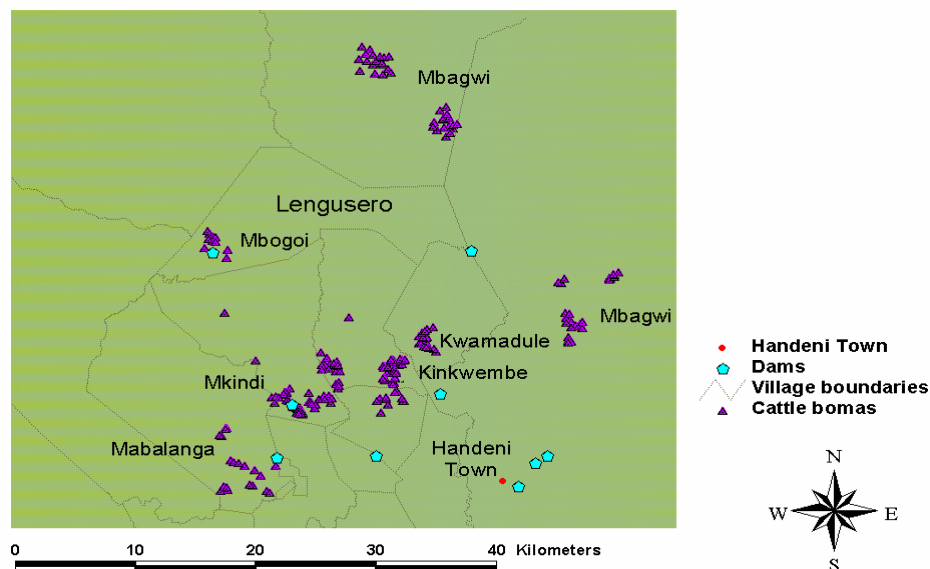


Fig. 6. Location of cattle bomas in Handeni project area.

Grazing practices.- In the wet season, most households let their cattle out between 9.00 – 10.00 h and they generally returned to their bomas at 17.00 h. In the dry season, the cattle left the bomas slightly earlier, (06.00 – 08.00 h) and returned slightly later (18.00 h). Grazing distances varied according to season and livestock owners. In general, the Maasai said that they graze further in the dry season (6 – 7km daily) than in the wet season (3 – 4km daily). The Zeguwa grazing patterns were similar, although they tended to graze over shorter ranges (4km in the dry season; 2km in the wet season).

All the groups, except the Zeguwa group from Kinkwembe, said that individual households herded their own cattle. Some of the Maasai households graze donkeys together with their cattle but in all villages, cattle are grazed separately from sheep and goats. Calves do not go out to graze with the adult herds; they are kept separately, nearer to the homestead, until ca. 6 - 9 months of age when they are allowed to join the adult herd.

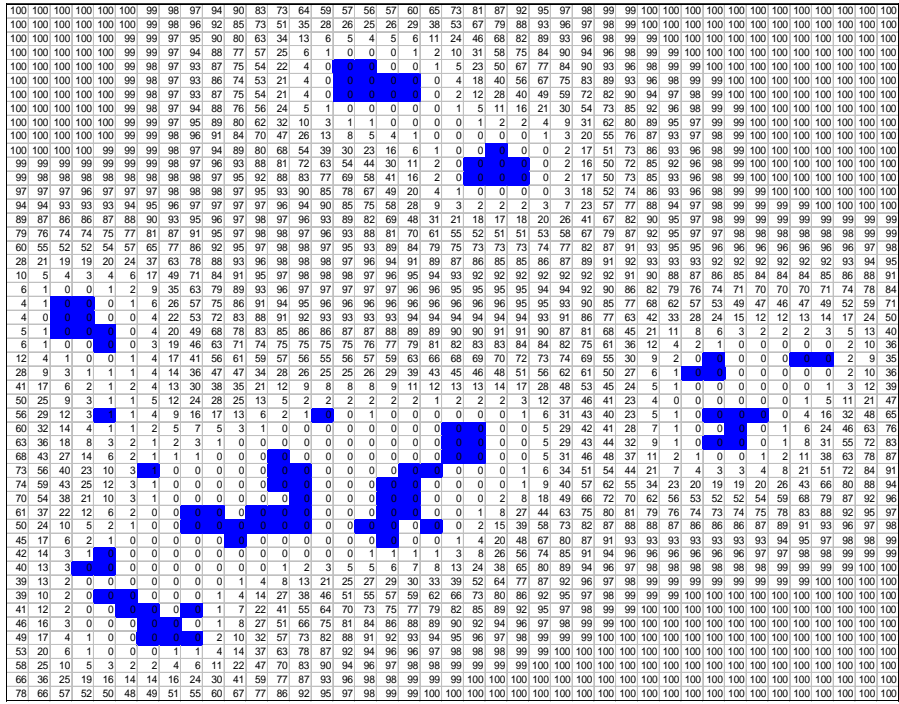
Despite the problems of feed- and water-shortage, most cattle owners do not shift grazing areas during the dry season. During the wet season cattle generally drink in the grazing areas, from rivers, shallow wells, small ponds and nearby dams. In the dry season they are taken to drink every other day: cattle from Mbogoi drink at Mbogoi dam; cattle from Mkindi and Mabalanga mainly drink at Mkuyu dam; and cattle from Kinkwembe and Kwamadule take their cattle to drink from the deep wells at Kwamadule. The distances that cattle graze in the dry season vary according to their water source(s).

Modelling

The map of cattle distributions in Handeni was used to predict the outcome of treating *all* the cattle in the Handeni study area (Fig. 7) with insecticide. The most important conclusion from the analysis was that using insecticide-treated cattle alone would not result in the complete eradication of tsetse. The predicted level of tsetse control in Handeni varied according to assumptions concerning (i) the grazing ranges of the cattle and (ii) the level of tsetse control produced by a herd as it passes briefly through an area. In the most optimistic scenario, where herds had a daily grazing range of 8 km and exerted a high tsetse mortality as they passed through an area, the use of insecticide-treated cattle should allow > 99% control within ~8 km of the villages. In the more pessimistic scenario, where the grazing range was 3 km and the tsetse mortality was lower, 99% control occurred only within ~3 km of the bomas. In both cases, tsetse numbers were predicted to increase rapidly beyond the range of the grazing area. The actual grazing ranges and tsetse mortalities range between the two extremes used in the models.

A second important practical implication of the model for Handeni was that the use of insecticide-treated cattle alone would benefit those areas where several villages are in close proximity (i.e. the area encompassing Mabalanga, Mkindi, Kinkwembe and Kwamadule) whereas the outlying villages of Mbagwe and Mbogoi, for instance, would benefit less (Fig. 7). Modelling further suggested that greater benefit could be derived by placing targets in those areas where cattle are either sparse or absent.

A. Pessimistic scenario with 3 km grazing ranges.



B. Optimistic scenario with 8 km grazing ranges.

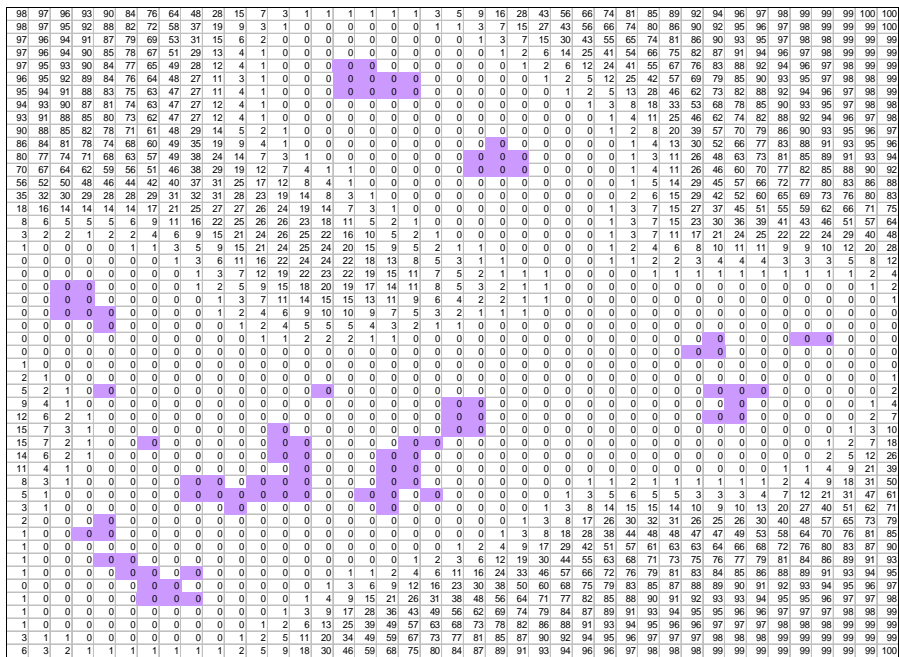


Fig. 7. Predicted outcome of treating all cattle with insecticide with either optimistic (A) or pessimistic assumptions concerning grazing ranges. Shaded areas indicate villages; each cell denotes 1 km² and the number in that cell is the estimated percentage of tsetse remaining after one year of control.

Stakeholder meetings in Handeni

The findings of the AHP research project were presented to staff from HIAP and the Ministry of Agriculture and Co-operatives (MoAC) at meetings in Handeni and Tanga. In addition, two joint stakeholder meetings with livestock owners, TDDP, HIAP and MoAC staff were held in Kwamadule and Mbagwe where ~100 livestock keepers from the Maasai and Zeguwa communities, including the village chairmen, attended. At the stakeholder meetings, the research results and the implications for community-based tsetse control in Handeni were presented in KiSwahili and KiMaasai. At the larger meeting, attended by ~75 livestock keepers, there was a vigorous discussion of the results and the implications. Particularly encouraging was a very realistic discussion of the costs and problems of community-based control. Several important matters such as theft of targets, fire, the relationship between the Zeguwa and Maasai communities and inequalities in cattle ownership were raised in the discussion.

Subsequently, discussions with HIAP, MoAC and TDDP staff focussed on various medium-scale tsetse operations in Handeni. The area covered by the study is >2000 km² and it was considered that attempting to control tsetse over this entire area was too ambitious in the first instance, especially given the patchy nature of cattle distribution. Accordingly, a phased approach, focusing initially on a smaller trial block where success would be more likely, was thought to be more appropriate. Following on from lessons obtained within the trial block, tsetse control could then be expanded to cover the neighbouring areas.

The option that currently seems to be most attractive from a technical point of view is, initially, to promote the use of insecticide-treated cattle in a trial area of ~750 km covering the villages of Mabalanga, Mkindi, Kinkwembe, Kwamadule and Mbogoi (Fig. 6). Monitoring within the trial area and in neighbouring villages outside the trial area would establish the epidemiological and economic efficacy of using pour-ons alone. In the light of monitoring tsetse numbers and distribution, targets could then be placed in areas where there are tsetse but few cattle. This strategy focuses on 170 households owning ~8000 of the ~12000 cattle mapped in the area. Moreover, the trial area includes all the significant watering points for these villages and the Maasai communities from the five villages are related. These features increase the likelihood of a successful outcome.

Pangani, Muhesa and Tanga Districts

Background

The second study area comprised some 500 km², comprising parts of Pangani, Muhesa and Tanga Districts (Fig. 8). The area was chosen largely because TDDP data had previously shown that this area is acutely affected by trypanosomiasis. For instance, in 1998 TDDP reported that 36% of cattle in Pangani contracted trypanosomiasis compared to <10% for all other districts in Tanga Region. Cattle ownership in the area comprises a mixture of zero-grazed cattle kept for dairy production and grazed cattle. Many cattle in the area are kept for milk production and consequently there is a higher-proportion of Zebu-Friesian crossbred cattle than in other areas.

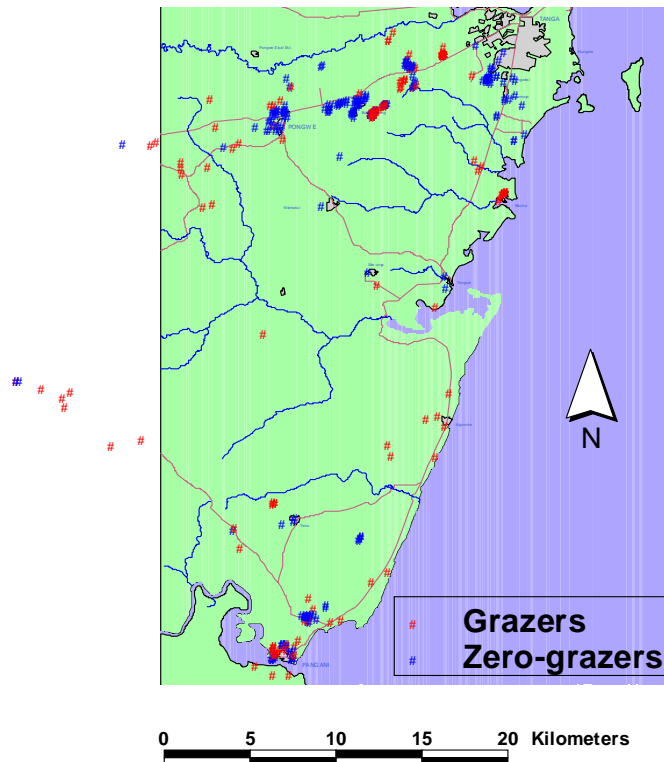


Fig. 8. Distribution of bomas in Pangani — Tanga study area. Each boma was classified as being either a grazing or zero-grazing household.

As was the case for Handeni, data on the number, distribution and management practices of cattle were collected together with information on the extent of the trypanosomiasis problem and current control measures being used.

Constraints to cattle production

Diseases were perceived as being a major problem in all locations (Table 4); 31% of the respondents ranked diseases as their biggest constraint and a further 56% ranked diseases either second or third. The second biggest problem was milk marketing, followed by feed shortage, cost and availability of drugs and finally lack of water.

Table 4: Importance ranking of main cattle problems (% of respondents)

	Rank 1	Rank 2	Rank 3
Milk marketing	31	19	0
Diseases	31	31	25
Feed shortage	19	6	19
Cost & availability of drugs	6	25	25
Lack of water	6	6	6
Other	7	13	25

Farmers considered that the main diseases were, in order of importance, ECF, trypanosomiasis, anaplasmosis, mastitis and worms (Table 5).

Table 5: Importance rank of cattle diseases (% of respondents)

	Rank 1	Rank 2	Rank 3
ECF	59	12	12
Trypanosomiasis	41	35	18
Anaplasmosis	0	29	47
Mastitis	0	12	0
Worms	0	0	12
Other	0	12	11

Again, as in Handeni, although trypanosomiasis is not directly responsible for the death of as many animals as ECF, trypanosomiasis was considered important because it is frequent, affects many animals, is expensive to treat and weakens animals thereby leaving them susceptible to other diseases.

Tsetse fly trap catches and bloodmeal analyses

Tsetse traps were set around Pangani and Pongwe for 25 trap/days in December 1998. The average catches per day were lower in Pongwe (less than 1 fly per trap per day) than in Pangani, (~12 flies per day). *G. pallidipes* was the predominant species but some *G. brevipalpis* and *G. austeni* were also caught. Analysis of fed flies caught on a farm near Pangani showed that 36% of meals were taken from cattle.

Table 6. Source of bloodmeals for *G. pallidipes* caught at Bushiri, Pangani District.

Host	Number of flies	Percentage (%)
Bushbuck, antelope etc.	33	56
Goats	1	2
Cattle	21	36
Donkeys	1	2
Warthogs and Wild Pigs	3	5

Current trypanosomiasis control

Data from farmer interviews suggest that livestock owners are using a wide range of strategies to control trypanosomiasis. All farmers interviewed reported using trypanocidal drugs. Berenil was most commonly used but there was some reported use of Samorin and Novidium. Farmers in Pangani were using Berenil to cure trypanosomiasis in sick animals but there were also examples of farmers using a regime of treating cattle at a fixed-interval with Berenil to prevent disease. Some livestock owners use both drugs and insecticides, although a greater proportion of grazers use both than do zero-grazers. A wide range of drugs and insecticides are being used (Berenil, Novidium, Samorin, Bayticol, Spoton, Dominex and Decatix) in different combinations and at different intervals.

To summarise, livestock owners in the Tanga Coastal area perceive trypanosomiasis to be an important disease, but tsetse catches indicate that the problem is less severe than in Handeni. There is also greater use of trypanocidal drugs at regular intervals in block treatments (as a preventative drug) and greater use of insecticides.

Cattle numbers and management practices

Herd sizes and compositions. - The positions and size of all the grazed and zero-grazed cattle herds in the project area were recorded. The results show that there are ~409 livestock owners and 5,330 head of cattle in the area (Table 7). The grazers make up the majority of the cattle in the area (4,589) and have a larger average herd size (29 cattle) than zero-grazers (3 cattle).

Table 7: Average size of cattle herds per household. Households were classified as being either grazers or zero-grazers.

	Average household herd size	Number of cattle owners	Total cattle
Grazers	29	249	4,589
Zero-grazers	3	160	741
Total	13	409	5,330

The cattle distribution in the Tanga coastal area is very patchy. There are concentrations of cattle around Pangani town, Tanga town and along the Tanga - Muhesa road but fewer cattle owners in the central area (Fig.8).

Grazing practices.- For zero-grazed cattle, the animals were kept continuously in a covered boma and all food and water was brought to the animal. For the grazed herds of cattle, the

grazing ranges were <3 km, although many grazing cattle were, on average, grazing within 1 km of their night boma.

Modelling

The map of cattle distributions in the Tanga Coastal area was used to predict the outcome of treating *all* the cattle in the study area with insecticide(Fig. 9). The predicted effect of using

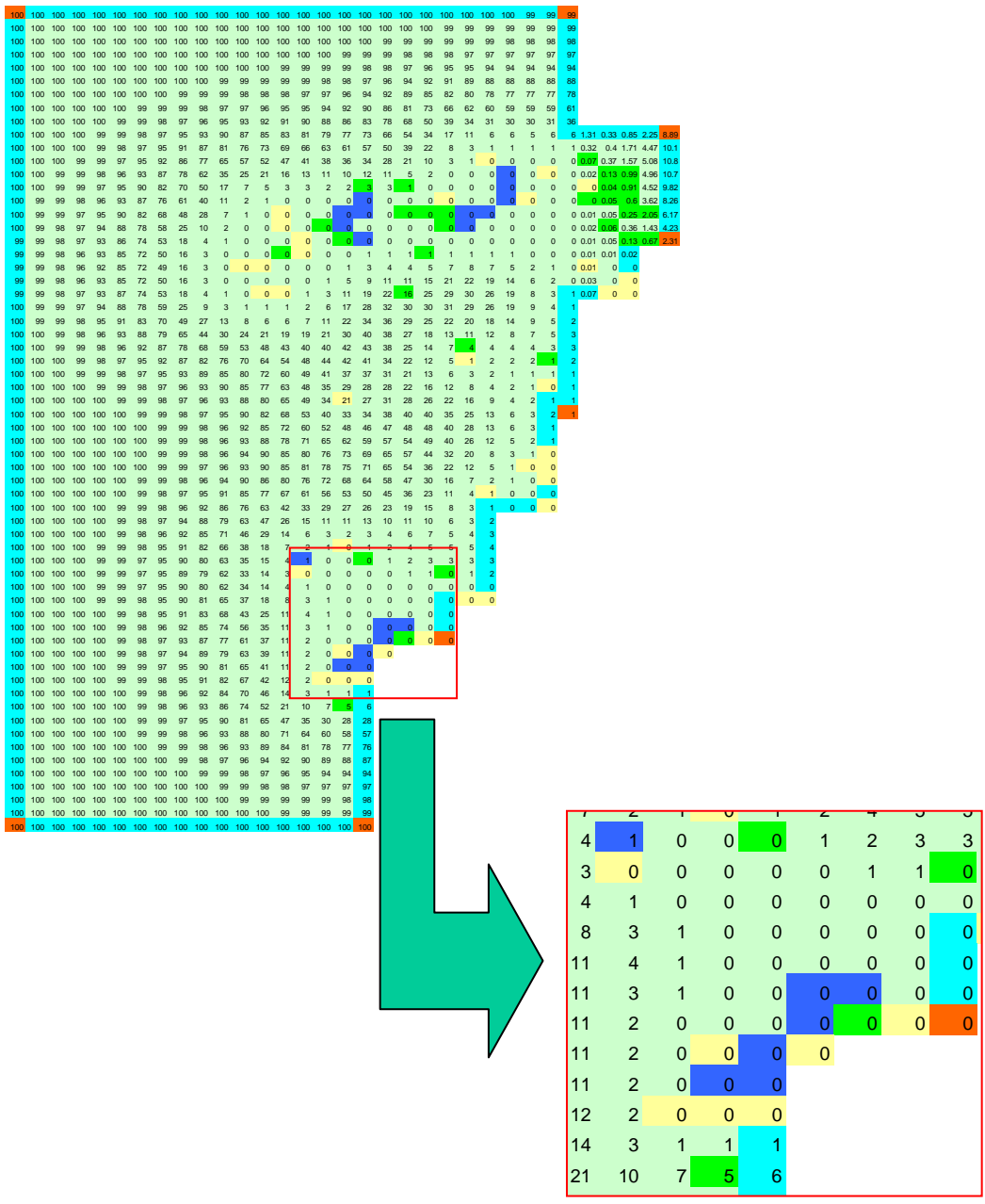


Fig. 9. Predicted outcome of treating all cattle with insecticide. Shaded areas indicate villages; each cell denotes 1 km² and the number in that cell is the estimated percentage of tsetse remaining after one year of control. Inset box shows detail in the vicinity of Pangani town.

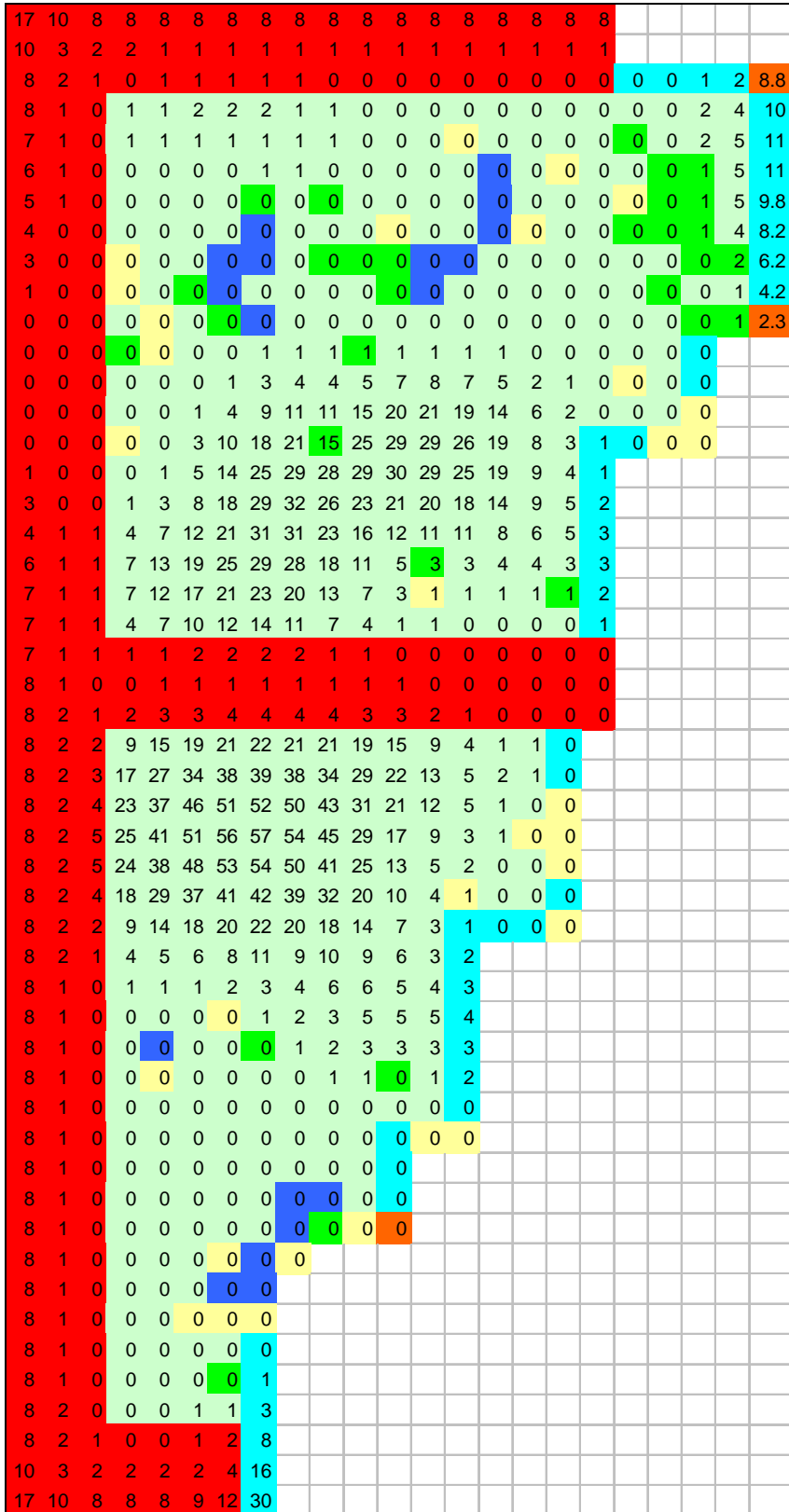


Fig. 10. Predicted outcome of treating all cattle with insecticide and deploying insecticide-treated targets (red-shaded area) at a density of 4/km². Shaded areas indicate villages; each cell denotes 1 km² and the number in that cell is the estimated percentage of tsetse remaining after one year of control.

insecticide-treated cattle in the area is markedly less successful than that observed or predicted for Mkwaja or Handeni. There is a reduction in the tsetse fly population to the 1% level in the neighbourhood of the towns with cattle, but the area around the towns which may be expected to stay relatively free of tsetse is much reduced. The predicted poor effect of using insecticide-treated cattle to control tsetse in the Tanga Coastal region is due to the low numbers, uneven distribution and smaller grazing ranges of cattle in the area.

The additional use of targets could lead to a dramatic improvement in the predicted tsetse situation. Thus, if a target barrier only 3-km wide and with 4 targets km^{-2} were deployed, as shown in an 'E' formation the tsetse population would collapse in a year to <10% in 90% of the cells within the barrier (Fig. 10). This intervention would only involve the use of 1000 targets. On the other hand the barrier would need to be maintained continuously, and even with its presence there would still be substantial pockets of fly within this area.

Stakeholder meetings

The findings of the research were presented to TDDP and MOAC staff at meetings in Tanga and Pangani. In addition, a joint stakeholder meeting of livestock owners, TDDP and MOAC staff was held in Pangani. Some 35 livestock owners from the Pangani area, representing ~40% of all owners, attended the meeting. At the stakeholder meeting, the research results, and the implications for community-based tsetse control in Pangani were presented in KiSwahili. Unlike the discussions in Handeni, the livestock owners in Pangani did not appear to explore or appreciate fully the problems of cost and community participation that are inherent in community based methods of controlling tsetse.

Subsequently, discussions with TDDP and MOAC scientists focussed on a number of small-scale tsetse operations in the Tanga Coastal Area. For instance, various tsetse control options for Pangani (Fig. 9, inset), an area of ~150 km^2 where ~550 grazed cattle and ~200 zero-grazed cattle are owned by ~80 households, were considered. The use of targets+insecticide-treated cattle to control tsetse was explored and it was felt that the costs of tsetse control are likely to prevent zero-grazers from participating. Thus while it may be technically possible to control tsetse, the generally low numbers of cattle and people, and their spatial distribution, may make tsetse control unfeasible. Accordingly, in this area, efforts may be better directed towards establishing methods of reducing disease by, for instance, protecting zero-grazed cattle using fly-proof bomas.

Contribution of outputs

The tsetse-affected regions of Africa are home to ~260 million people. For many livestock owners in this area, the cheapest technical option for controlling tsetse is to treat their cattle with insecticide. However, experience with the technique has been variable and consequently livestock owners, and institutions concerned with controlling trypanosomiasis, are forced to gamble limited resources on an uncertain outcome. This project aimed to address this problem by providing a rational framework for predicting the outcome of using insecticide-treated cattle to control tsetse.

Output 1. Establish quantitative relationships between cattle density/distribution and cattle-tsetse contact in Zimbabwe and Tanzania

The project quantified the effect of herd size and composition on the numbers of tsetse contacting the herd and hence, by implication, the numbers of tsetse killed by a herd of insecticide-treated cattle. Furthermore, the project undertook experiments to determine whether specific herding practices, such as placing cattle in kraals or the presence of a herder, affected tsetse-cattle contact. The results indicate that for herds typically found in tsetse-affected areas of east and southern Africa, the numbers of a tsetse killed by a herd of insecticide-treated cattle will be a curvilinear function of the herd's liveweight.

Results, obtained in the process of undertaking this research, indicate that tsetse were preferentially feeding, and hence contacting, certain 'attractive' animals within a herd. The data suggest that these attractive animals are the older and/or larger animals within the herd. This finding may have potential practical benefits since it suggests that the cost-effectiveness of the technique could be improved by treating only the more attractive animals within the herd.

Existing published data on rates and patterns of fly movement and population growth were used to derive a general simulation model of the growth and movement of tsetse populations. Further published data on the mortality produced by insecticide-treated targets and cattle were used to develop a general model of the effects of insecticide-treated targets on tsetse populations. The model uses a spreadsheet, whose cells are taken to represent blocks of land, and thus spatial variation in the density of cattle, targets and tsetse can be reflected in the model. The model can be readily adapted to suit any distribution of baits and assumed rates of tsetse growth and movement and, consequently, can be applied to any population of tsetse.

A combination of socio-economic and traditional mapping techniques was used to map cattle distributions from tsetse-affected sites in Zimbabwe and Tanzania. These data were analysed, using the simulation model, to provide a quantitative explanation of the observed outcome of various tsetse control operations. The results showed that the most important variable affecting the outcome of control operations based on the use of insecticide-treated cattle is the evenness of the cattle distribution. This is, in turn, affected by various factors including: herd size, grazing range, the distribution of water and pasture resources.

Output 2. Produce recommendations on the suitability of insecticide-treated cattle to control tsetse in the three project areas in particular and tsetse-infested areas of Africa in general.

Zimbabwe

The studies in Zimbabwe have explained why a barrier of insecticide-treated cattle is not technically effective in areas where cattle numbers are insufficient and/or are unevenly distributed (both in their kraals and whilst grazing). Thus the wisdom of the Government of Zimbabwe's current policy of employing a barrier of insecticide-treated cattle is confirmed.

The socio-economic studies are the first objective assessment of the perceptions of communal farmers towards tsetse control and the findings highlight the conundrum facing the Government of Zimbabwe. On the one hand, financial pressures require that livestock owners contribute more towards the costs of dipping animals for tsetse and tick control. On the other hand, farmers feel that the costs are not justified by the disease risks and are thus unwilling to contribute more. Farmers are currently paying <10% of the estimated Z\$40/animal/year cost of treatment. The success of the tsetse- and tick-control schemes means that few farmers have suffered losses to these diseases in recent years and, consequently, farmers do not rank trypanosomiasis as being important. It is clear that if farmers are to contribute more towards control, then farmers in commercial and communal sectors need to be educated as to the risks, costs and benefits of control and any cost-recovery system needs to be designed with these perceptions in mind. The Tsetse Control Branch has drafted a research and development strategy which includes activities aimed at addressing this need.

Tanzania

The EU-funded Farming in Tsetse Controlled Areas (FITCA) programme is promoting community-based methods of tsetse control in Tanzania, Kenya, Uganda and Ethiopia. In Tanzania, it plans to link with the Tanga Dairy Development Project (TDDP) and Handeni Integrated Agroforestry Project (HIAP) in Tanga Region, where tsetse-borne diseases are a major constraint to the livelihoods of smallholder livestock keepers. The proposed project areas coincide with those studied in this project and thus the site-specific research findings are particularly germane to the FITCA programme.

The findings indicate that the use of insecticide-treated cattle alone is insufficient to control tsetse in the survey areas, particularly in Tanga district, but it may provide some level of local control and could be effectively combined with strategically placed odour-baited targets. The socio-economic survey results also support the potential suitability of the technique. Cattle are very important in the livelihoods of smallholders in both study areas, particularly for the Maasai in Handeni and the zero-grazing dairy farmers in Tanga. Trypanosomiasis is one of the major constraints to cattle production and, the current direct and indirect costs of the disease are considerable. Furthermore, in contrast to the Zimbabwe situation, government support for livestock services in Tanzania is non-existent, so the costs are already borne by the farmers themselves. A greater interest in, and willingness to contribute towards, community tsetse control schemes using insecticide-treated cattle and/or targets was therefore more evident in Tanzania.

In March 2000, stakeholder meetings were held in Handeni and Pangani with livestock owners and staff from governmental (Ministry of Agriculture and Co-operatives, MoAC) and donor institutions (TDDP, HIAP) concerned with supporting livestock owners. Following these meetings and subsequent discussions, a project seminar and technical report

were produced for the institutions (TDDP, HIAP and MoAC) concerned with submitting a project proposal to FITCA. Subsequently, a joint proposal was submitted to FITCA and this submission includes a phased plan for tsetse control over ~2000 km² of Handeni and proposals to develop strategies to enable individual livestock keepers to reduce the risk of trypanosomiasis in Tanga.

Africa

The project findings provide a general framework for predicting the outcome of proposed control schemes involving insecticide-treated cattle. The approach provides not only guidance for specific control operations but also general insights into various tsetse control strategies. Such general recommendations have been disseminated via the internet and more traditional media such as presentations at conferences, seminars and papers published in international journals.

Publications.

The following papers by project scientists on matters related to this project were published in international journals in 1998-2000.

- Gibson, G. & Torr, S.J.** (1999). Visual and olfactory responses of haematophagous Diptera to host stimuli. *Medical and Veterinary Entomology* **13**, 2-23.
- Hargrove, J. W., Omolo S., Msalilwa, J.S.I. & Fox, B.** (2000). Insecticide-treated cattle for tsetse control: the power and the problems. *Medical and Veterinary Entomology*, (in press).
- Hargrove, J.W. & Williams, B.G.** (1998). Optimized simulation as an aid to modelling, with an application to the study of a population of tsetse flies, *Glossina morsitans morsitans* (Diptera: Glossinidae). *Bulletin of Entomological Research* **88**, 425-435
- Hargrove, J.W.** (2000). A theoretical study of the invasion of cleared areas by tsetse flies (*Glossina* spp). *Bulletin of Entomological Research*, (in press)
- Torr, S.J. & Hargrove, J.W.** (1998). Factors affecting the landing and feeding responses of the tsetse fly *Glossina pallidipes* to a stationary ox. *Medical and Veterinary Entomology* **12**, 196-207.
- Torr, S.J. & Mangwiro, T.N.C.** (2000). Interactions between cattle and biting flies: effects on the feeding rate of tsetse. *Medical and Veterinary Entomology*, (in press).

A further

Internal Reports:

Internal reports were produced on the following overseas visits:-

Country	Scientist	From	To
Zimbabwe	Torr	23 March 1998	23 April 1998
Zimbabwe	Torr	1 July 1998	15 July 1998
Zimbabwe	Torr	9 September 1998	8 October 1998
Tanzania	Torr	1 December 1998	19 December 1998
Zimbabwe	Torr	13 January 1999	5 February 1999
Zimbabwe	Kindness	26 January 1999	22 February 1999
Zimbabwe	Torr	7 April 1999	1 May 1999
Zimbabwe	Torr	8 September 1999	3 October 1999
Zimbabwe	Torr	6 November 1999	12 November 1999
Tanzania	Kindness & Torr	21 June 1999	21 July 1999
Tanzania	Kindness	23 August 1999	8 September 1999
Tanzania	Kindness & Torr	6 March 2000	17 March 2000

Other Dissemination of Results

During the visits to Zimbabwe, presentations on various aspects of the project were made to staff of the Zimbabwe Tsetse and Trypanosomiasis Control Branch and the Regional Tsetse and Trypanosomiasis Control Programme. In Tanzania, seminars were held with staff from Tanga Dairy Development Project, Tsetse and Trypanosomiasis Research Institute (TTRI) and the Livestock Training Institute (LITI - Buhiri). At the end of the project, presentations were made, in KiSwahili and KiMaasai, to livestock owners to assist them, and their supporting institutions, in making rational decisions regarding various technical options for controlling tsetse.

In addition, the following presentations were made at scientific meetings:-

- Hargrove, J.W.** (1998). Review of tsetse research in the RTTCP region. Paper presented at regional technical meeting of the Regional Tsetse and Trypanosomiasis Control Programme (Harare, 16 September 1998).
- Hargrove, J.W.** (1998). Insecticide-treated cattle: the power and the problem. Paper presented at the Programme Against African Trypanosomiasis (PAAT) meeting. Harare, Zimbabwe, 21 October 1998.
- Schofield, S., Sutcliffe, J. & Torr, S.J.** (1998). The influence of host-defensive behaviour on the feeding strategies of tsetse flies and stable flies. Paper presented (by Dr Schofield) at the annual meeting of the Canadian Entomological Society, Quebec, Canada, November 1- 4, 1998.
- Tanga Dairy Development Programme** (1999). Kinga ya Ndorobo – Tanga. *Akili ni Mali* ('Wisdom equals Wealth' in KiSwahili) **4**, 2-3.
- Zollner G.E., Torr S.J., Ammann C. & Meixner F.X.** (1998). Carbon dioxide plume distribution: implications for host location in tsetse. Poster and proceedings paper presented (by Dr Ammann) at 13th Conference on Biometeorology & Aerobiology (Albuquerque, NM, USA), 2-6 November 1998.
- Mangwiro, T.N.C., Kindness, H.M., Torr S.J., Hall D.R. and Hargrove J.W.** (1999). Cattle management practices in tsetse-infested areas of Zimbabwe: implications for tsetse control. Paper presented at the ISCTRC meeting, Mombasa, Kenya (September 1999).
- Richards, W., Torr, S. & Budd, L.** (1999). Tsetse take the bait. Paper presented at the DFID symposium on: "*Eliminating Poverty: the Value of Science to Rural Livelihoods*" in London, UK (October 1999).

Follow-up indicated/planned:

Tsetse control in Tanzania

The EU-funded 'Farming in Tsetse Controlled Areas' (FITCA) programme aims to support community-based schemes for controlling tsetse in East Africa. In Tanzania, these schemes will be managed by the Dutch-funded TDDP and the German-funded HIAP projects. Accordingly, these projects produced a plan for community-based tsetse control in the Pangani and Handeni Districts of Tanga Region based largely on the outputs of this project. The proposals are currently being considered by the FITCA office in Nairobi.

Tsetse control in Zimbabwe

The use of insecticide-treated cattle will continue to form a component of tsetse control in NE Zimbabwe, funded entirely by the Government of Zimbabwe.

Research

The outputs of the current project suggest that future research should be directed at answering four questions which underlie many of the uncertainties concerning community-based tsetse control.

1. Can the use of insecticide-treated cattle be made more cost-effective?

Research undertaken by this project indicated that tsetse attracted to a herd of cattle contact the older and larger cattle. This finding suggests that the cost-effectiveness and acceptability of using insecticide-treated cattle to control tsetse, and hence trypanosomiasis, could be improved by applying insecticide selectively to only the attractive animals within an owner's herd. A DFID-funded research project is currently investigating this possibility by sampling tsetse as they visit herds of cattle. The individual source(s) of bloodmeals of the sampled flies are then determined directly, using a novel molecular methodology. These data will then be incorporated into simulation model(s) to predict the cost-effectiveness of selective insecticide-treatment strategies.

2. What is the long-term sustainability of using trypanocidal drugs?

In Tanzania, the main method of controlling trypanosomiasis is the use of trypanocidal drugs. These drugs are widely available but their use is largely uncontrolled and there is little advice available to farmers on the appropriate use of these drugs. This situation is likely to exacerbate the emergence of drug resistance in Tanzania; there is good evidence of resistance to both Samorin and Berenil in Pangani District for instance. Consequently, there is a need for research to:-

- Quantify the extent of drug resistance in the project areas;
- Develop appropriate strategies for the effective use of trypanocidal drugs and;
- Develop appropriate extension materials on the use of drugs for farmers.

These research needs could be addressed by linking with the EU- and DFID-funded Kenya-based research projects concerned with the use of trypanocides.

3. *What is the relationship between different levels of tsetse control and subsequent improvements in disease incidence and animal productivity?*

The tsetse control options being considered in Tanzania will not eradicate tsetse and thus farmers will continue to use trypanocidal drugs to some degree. It is to be expected therefore, in the short-term at least, that farmers who take up tsetse control will experience an increase in the costs of controlling trypanosomiasis. The expected longer-term benefits of this extra expenditure are decreased costs of treating disease and increases in animal productivity. Consequently, a basic understanding of the relationships between tsetse abundance, disease risk and animal productivity is required so that a rational integrated strategy for controlling trypanosomiasis can be developed. Such research should be aimed at establishing:-

- Quantitative relationships between the bait density and distribution patterns required for effective control of tsetse and the level of trypanosomiasis risk.
- The economic, health and productivity costs and benefits of different tsetse control options assessed through their impact on tsetse and tick-borne diseases.
- Recommendations on the integrated use of tsetse baits and trypanocidal drugs at a local level to reduce trypanosomiasis risk in Tanzania and tsetse-infested areas of Africa in general.

4. *Apart from drugs, are there any technologies that can be used by poor, individual livestock keepers to reduce the risk of trypanosomiasis?*

The high mobility of tsetse means that areas cleared of fly are susceptible to rapid re-invasion from adjacent infested areas. Accordingly, concerted action by institutions and/or communities over large areas and long periods is the only proven method of controlling tsetse. In areas where farmers are poor and/or the densities of owners and cattle is low, large-scale tsetse control by communities is impossible. In Tanzania, we found several instances of individual livestock owners using various cultural methods to reduce contact between tsetse and cattle. Moreover, there is good evidence that various physical and chemical stimuli can reduce the numbers of tsetse attracted to cattle. We suggest that research should be directed at identifying and quantifying the effects of these cultural practices and stimuli with a view to developing technologies that individual farmers could use to protect their cattle from trypanosomiasis.

Research addressing parts of question 1 is currently being undertaken by a DFID-funded project in Kenya while research aimed at addressing questions 3 and 4 were the subject of two unsuccessful proposals submitted to the DFID Animal Health Programme in September 1999. Currently, some of the above research proposals form part of the proposed FITCA programme.