CHAPTER FOUR

BOVINE TRYPANOSOMOSIS AS A HERD DISEASE AND AN ASSESSMENT OF ITS SOCIO-ECONOMIC IMPACTS

4.1 Introduction

An important determinant in the selection of priority areas for the control of bovine trypanosomosis is the effect of the disease on agricultural development. These effects can be either direct or indirect (Section 1.4.3). The indirect socio-economic impacts of nagana are often difficult to qualify and quantify. They are a result of the effects of the disease on agricultural production and farming practices. They are likely to be affected by factors other than trypanosomosis and are, therefore, subject to temporal and spatial variability. Hence, the indirect effects of trypanosomosis can only be quantified and qualified after a thorough analysis of the farming system and the factors constraining it. Most of the direct effects, on the other hand, can be quantified relatively easily.

The direct effects of bovine trypanosomosis and its control on herd productivity are a result of changes in the health status and performance of cattle in areas under challenge. The proportion of infected animals and disease tolerance, to a large extent, determines the health status of a herd. A wide range of factors can increase an animal's susceptibility to trypanosomosis (Section 1.4.2.2). Hence, susceptibility is also subject to temporal and spatial variations. With bovine trypanosomosis, tolerance to the disease is associated with an animal's ability to control the intensity, prevalence and duration of parasitaemia and to limit the pathological effect of parasites, the most prominent of which is anaemia. Consequently, the relationship between prevalence of trypanosomal infections in a herd and the herd's average packed cell volume could be a useful indicator of disease tolerance. A study was undertaken to investigate this relationship and the usefulness of this relationship as an adjunct to the rapid assessment of the impact of bovine trypanosomosis (Section 4.2).

Bovine trypanosomosis is considered to be one of the major constraints to livestock development in large parts of southern Africa. Despite the perceived importance of the disease, the real impacts of nagana on productivity are unknown. This is surprising since the sustainability of a control intervention will depend largely on the benefits accruing from such an intervention. To quantify the impact of bovine trypanosomosis on production and predict the potential impacts of controlling the disease under the different epidemiological situations occurring in the southern African region socio-economic surveys were conducted. Information was collected about the proportion of households directly affected by the disease, cattle marketing practices and cattle productivity under different epidemiological situations and current disease management practices (Section 4.3). Conclusions were then drawn about the socio-economic impact of trypanosomosis control.

4.2 The relationship between the parasitological prevalence of trypanosomal infections in cattle and herd average packed cell volume

4.2.1 Introduction

The distribution of tsetse-transmitted bovine trypanosomosis is usually established by demonstrating trypanosomal infections in cattle. By comparing the proportion of infected animals between herds, areas of low, medium or high disease prevalence can be distinguished from disease-free areas. Several factors including trypanosome strain, age of the infected animal, breed and nutritional status affect the tolerance of trypanosomal infections in susceptible breeds (Connor, 1994a). Therefore, decisions to intervene and control trypanosomosis cannot be based solely on the presence of trypanosome-infected animals but should be supported by an assessment of the impact of the infection on animal condition and, hence, animal production. In cattle and other domestic animals, anaemia is a well-recognized and inevitable consequence of an infection with pathogenic trypanosomes (Murray and Dexter, 1988). It is best measured by determining the PCV. In the absence of other factors causing anaemia, the PCV gives a reliable indication of the disease status of a trypanosome-infected animal and is strongly correlated with its performance (Trail *et al.*, 1991; 1993). Consequently, the herd average PCV should give a good indication of the health status of a herd. Furthermore, by establishing the relationship between herd average PCV and prevalence of infection in an area, useful information can be obtained on (i) the impact of various levels of disease prevalence on herd health and (ii) the likely impact of control interventions on herd health. Although the herd average PCV is expected to decrease with increasing prevalence of trypanosomosis, this relationship has not been quantified sufficiently. Data obtained from trypanosomosis surveys conducted in eastern Zambia were used to study this relationship in more detail. The usefulness of this relationship as an adjunct to the rapid assessment of the impact of bovine trypanosomosis is discussed.

4.2.2 Materials and methods

The herd mean prevalence of trypanosomal infections and herd mean PCV were obtained from cattle sampled at 141 sampling sites (crushpens) in Katete, Petauke, Chipata and Lundazi Districts (Chipangali area) of eastern Zambia. All districts are ecologically similar, have similar farming systems (RTTCP, 1998; 1999) and are situated on the eastern plateau. Bovine trypanosomosis, transmitted by *G. m. morsitans*, is endemic. Bovine trypanosomosis is managed using trypanocidal drugs mainly diminazene aceturate (Berenil ®, Hoechst). The proportion of animals treated and the treatment frequency is low (Section 5.2.3). Two separate disease surveys were conducted. The first survey covered all four districts. It was conducted during the rainy season (November-March 1996). Sampling sites were selected depending on their location and were evenly spread over each district. During a second survey, sampling was repeated at the sampling sites in Petauke District only but different animals were sampled. The second survey was conducted during the dry season (August-September 1996).

A "random" sample of communally managed adult cattle (Angoni breed) was selected at each sampling site (Section 3.4.2.1). The buffy coat, stained thick and stained thin smears were used as parasitological diagnostic methods (Section 3.3.2.2). The PCV of each blood sample was determined. The level of bovine trypanosomosis at a sampling site was calculated as the proportion of cattle with a trypanosomal infection; it is henceforth referred to as "herd prevalence". The PCV of all animals sampled at each site was averaged; this is referred to as the "herd average PCV". From all animals, blood contained in one heparinized microhaematocrit centrifuge capillary tube was extruded onto a filter paper (Whatman n° 4, Whatman®). Eluted blood spots were screened for the presence of trypanosomal antibodies using an indirect ELISA (Section 3.3.2.2).

The relationship between the parasitological prevalence of trypanosomal infections and herd average PCV was examined by regression analysis using the estimates of herd average PCV as the dependent variable and the prevalence of trypanosomal infections in a herd as the independent variable. The effects of area of sampling (district) and season of sampling on the herd average PCV was also investigated by analysis of variance using data obtained from the four districts in Zambia during the rainy and one district during the dry season. In addition use was made of a multiple linear regression model with herd average PCV as the dependent variable and combinations of season, area of sampling (district) and herd prevalence of trypanosmal infections as independent variables.

The models fitted were:

$y_{ij} = a + d_i + b_i x_{ij} + r_{ij}$ for all four districts ($i = 1, \ldots, 4$) during the rainy season and

$y_{ij} = a + s_i + b_i x_{ij} + r_{ij}$ for rainy and dry season ($i = 1, 2$) for herds in Petauke District

where y_{ij} = herd PCV for herd j within respectively district or season i

a = average intercept

d_i ($i = 1,\ldots,4$) = effect of district on mean herd PCV

s_i ($i = 1, 2$) = effect of season on mean herd PCV

b_i = regression coefficient for district in season i

x_{ij} = prevalence of trypanosomal infections in a herd

r_{ij} = residual

All analyses were performed using the statistical package SPSS (SPSS Inc.).

4.2.3 Results

A total of 8 640 head of cattle were sampled in four districts (Chipata, Lundazi, Petauke and Katete) of the Eastern Province of Zambia. Trypanosomal infections, mainly due to *congolense* (86.4%), were detected in 1 252 animals (14.5%) from 97 herds out of a total of 141 herds sampled.

The herd average prevalence of trypanosmal infections in the rainy season varied between areas. It was highest in the Petauke and Lundazi Districts and lowest in Chipata District (Table 4.2.1).

Table 4.2.1: Number of herds sampled, number of trypanosome-positive herds, average parasitological prevalence of trypanosomosis and average PCV of parasitological positive and negative herds in four districts of the Eastern Province of Zambia during the rainy season and in Petauke District during the dry season.

Area	Season	Number of herds sampled	Number of positive herds	Average prevalence (% ± 1 s.e.)	Average PCV (% ± 1 s.e.)	
					positive herds	negative herds
Chipata	rain	21	10	8.4 ± 2.3	29.9 ± 0.9	31.8 ± 0.8
Katete	rain	16	13	11.4 ± 1.6	27.7 ± 0.7	29.7 ± 0.8
Lundazi	rain	22	22	17.8 ± 1.8	27.1 ± 0.5	-
Petauke	rain	43	38	24.7 ± 2.8	26.5 ± 0.3	29.6 ± 0.9
Petauke	dry	39	39	26.1 ± 4.2	26.1 ± 0.5	-

The average PCV of parasitologically positive herds decreased with increasing average prevalence of infection. The majority of the parasitologically negative herds (68.4%) contained animals with anti-trypanosomal antibodies. However, the herd average PCV of parasitologically negative and seronegative herds (31.8 ± 1.2%, n = 6) did not differ from the average herd PCV of parasitologically negative but seropositive herds (30.5 ± 0.5%, n = 13) (Fig. 4.2.1)

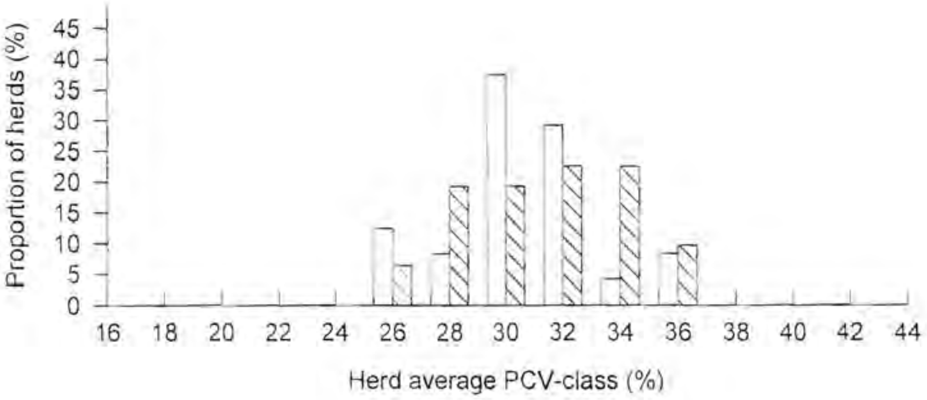


Figure 4.2.1: Frequency distribution of average packed cell volume (PCV) of parasitologically negative herds that are serologically negative (□) and serologically positive (▨).

In all areas, regression analyses showed that the herd average PCV of parasitologically positive herds decreased with increasing prevalence of trypanosomal infections (Table 4.2.2).

Table 4.2.2: Linear regression of herd average PCV (%) on parasitological prevalence of trypanosomosis (%) in four districts of the Eastern Province of Zambia during the rainy season.

Area	Season	Number of herds	a[*]	b[*]	r[*]	Significance
Chipata	rainy	10	32.8 ± 0.8	-0.35 ± 0.08	0.84	P<0.001
Katete	rainy	13	31.3 ± 1.3	-0.31 ± 0.11	0.65	P<0.05
Lundazi	rainy	22	30.6 ± 0.9	-0.20 ± 0.04	0.71	P<0.001
Petauke	rainy	38	28.4 ± 0.4	-0.08 ± 0.02	0.65	P<0.001

[*] a = intercept (± 1 s.e.)
b = regression coefficient (± 1 s.e.)
r = correlation coefficient

Removal of district from the multiple linear regression model did not result in a significant change in its fit (P > 0.05). Hence, the intercepts for area of sampling shown in Table 4.2.2 were not significantly different. The slope of the equation between mean PCV and trypanosome prevalence (parameter b in Table 4.2.2), however, decreased with increasing prevalence of trypanosomal infections suggesting a curvilinear relationship with PCV (Fig. 4.2.2). Season of sampling also affected the slope of the equation between mean PCV and trypanosome prevalence (parameter b in Table 4.2.3).

Table 4.2.3: Linear regression of herd average PCV (%) on parasitological prevalence of trypanosomosis (%) in Petauke District of the Eastern Province of Zambia during the rainy and dry season.

Area	Season	Number of herds	a[+]	b[+]	r[+]	Significance
Petauke	rainy	38	28.4 ± 0.4	-0.08 ± 0.02	0.65	P<0.001
Petauke	dry	39	28.3 ± 0.6	-0.20 ± 0.03	0.71	P<0.001

[+] a = intercept (± 1 s.e.)
b = regression coefficient (± 1 s.e.)
r = correlation coefficient

For the same increase in prevalence of infection, the decrease in herd average PCV was higher in the dry compared to the rainy season (P<0.01) (Table 4.2.3 and Fig. 4.2.3).

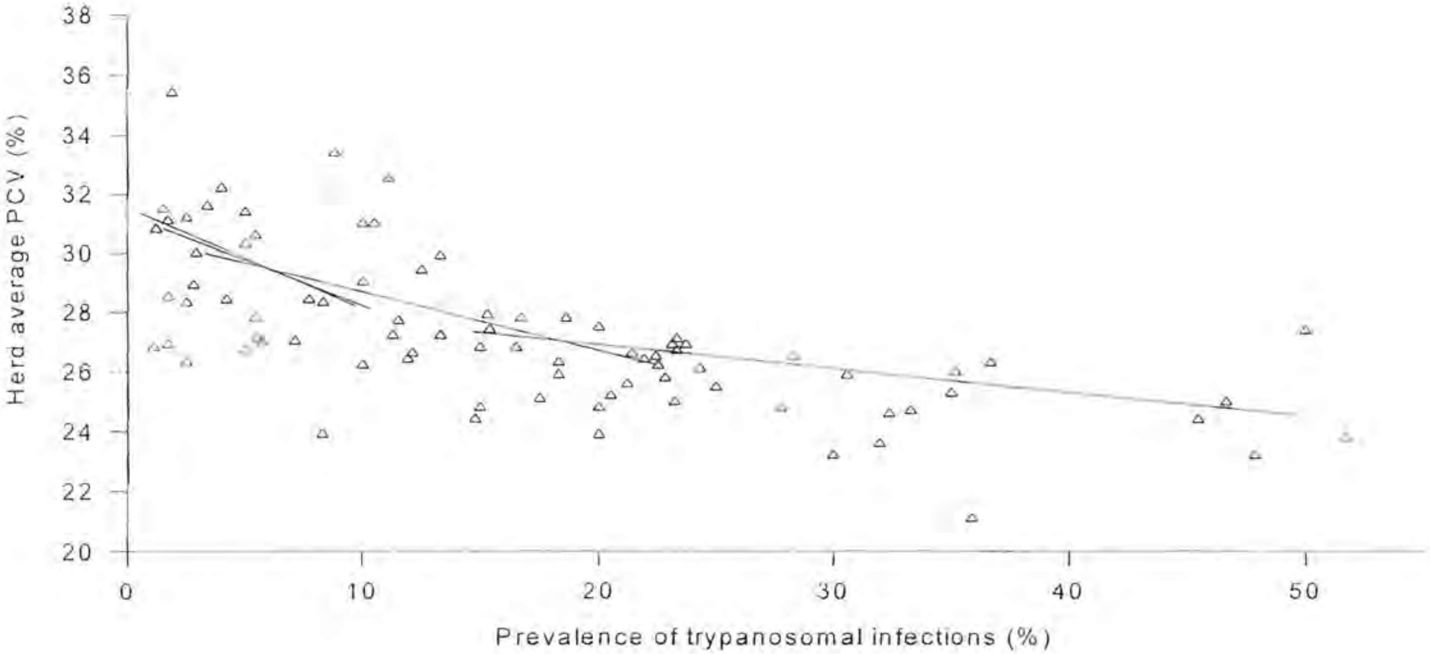


Figure 4.2.2: Relationship between herd average PCV and prevalence of trypanosomal infections in herds sampled during the rainy season in eastern Zambia. Lines are fitted by linear regression; see Table 4.2.1 for parameter estimates and significance levels.

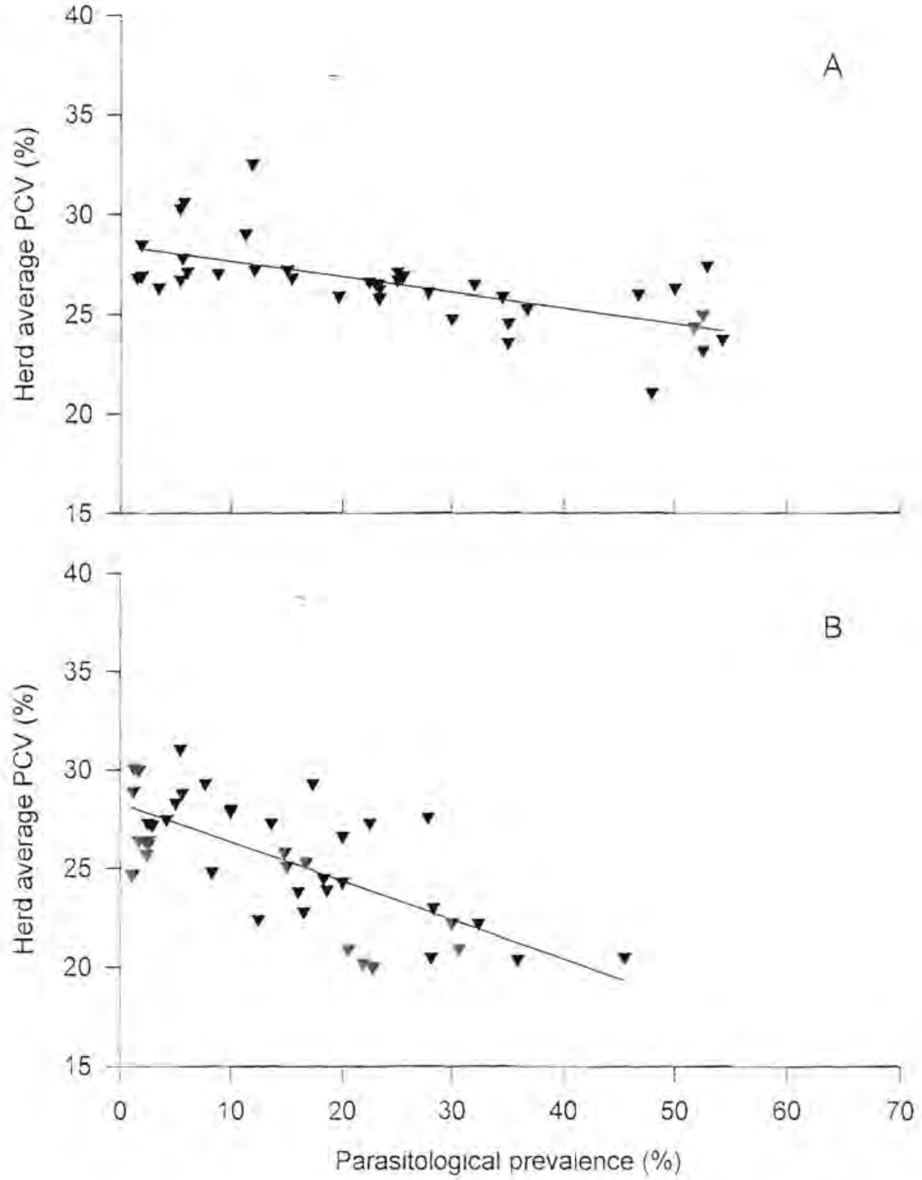


Figure 4.2.3: Relationship between herd average PCV and parasitological prevalence of trypanosomal infections in herds sampled during the rainy (A) and dry (B) season in Petauke District.

4.2.4 Discussion

The development of anaemia is one of the most typical signs of trypanosomosis caused by *T. congolense* in susceptible cattle breeds (Murray and Dexter, 1988). The level of anaemia, as indicated by the PCV, usually gives a reliable indication of the disease status and productive performance of infected animals (Trail *et al.* 1991, 1993). Bovine trypanosomosis control aims at reducing the prevalence of infection with a concomitant increase in the herd average PCV (Bauer *et al.*, 1999). Nevertheless, reduction in trypanosomosis prevalence does not necessarily result in an increase in the herd average PCV (Rowlands *et al.*, 1996). Therefore, establishing the relationship between the prevalence of trypanosomal infections and herd average PCV is a useful tool in the preliminary assessment of the expected impact of a control intervention. Conversely, the slope of the regression line can be used as an indicator of the impact of trypanosomosis on herd average PCV and, hence, herd health. By comparing the slopes, temporal and spatial comparisons could be made of the impact of trypanosomosis. However, the herd average PCV is affected by factors other than trypanosomosis (Connor, 1994b). These confounding factors are not always easily identifiable but they are likely to affect both trypanosomosis positive and negative animals. Hence, the average PCVs of trypanosomosis-free herds are a good indicator of the levels of anaemia in the absence of trypanosomosis and could form the baseline for comparison between areas. Determining the PCV-distribution of parasitologically negative herds may be difficult with parasitological diagnostic methods of low sensitivity at the individual animal level (Paris *et al.*, 1982). However, according to the above results, the herd-level sensitivity of the buffy coat method for the detection of at least one positive sample in a positive herd is high at the sample sizes used in the survey (Martin *et al.*, 1992). Indeed, the herd average PCV of parasitologically negative herds does not differ from the herd average PCV of serologically negative or true negative herds. The PCV-distribution of the parasitologically negative herds can thus be used as the baseline herd average PCV distribution in the absence of trypanosomosis.

The slope of the regression equation between PCV and trypanosome prevalence decreased with increasing prevalence of trypanosomal infections. Hence, for the same increase in prevalence, the decrease in herd average PCV is lower in herds under high challenge compared to herds under low challenge. This could be explained by differences in trypanocidal drug use. The effect of increased prevalence of infection on PCV would, for example, be minimal if the majority of drug treatments were given in the early stages of infection before or during the early phase of anaemia development. Such a trypanocidal drug treatment regimen requires early diagnosis of the trypanosomal infection. Diagnostic facilities are, however, not readily available in the study area. Hence cattle owners mainly treat clinically sick animals in the later stage of infection when, often severe, anaemia has developed (Section 5.2.3).

For the same increase in the prevalence of infection, the decrease in herd PCV is higher in the areas with low to medium prevalence (Chipata and Katete Districts). In the absence of an effect of trypanocidal drug use, the main factor determining the slope of the equation between PCV and trypanosome prevalence is the infected animal's ability to control the development of anaemia. This will differ between cattle breeds and will be affected by factors such as intercurrent disease, nutrition and the level of acquired immunity. The effect of cattle breeds is well-known. The development of anaemia tends to be more severe in exotic breeds whereas it is well-controlled in trypanotolerant breeds (d'Ieteren *et al.*, 1998). All cattle sampled during the survey were of the trypanosusceptible Angoni breed. The effect of the other factors on the relationship between prevalence and PCV is difficult to quantify. Differences in the prevalence of intercurrent diseases, aggravating the effect of trypanosomal infections on PCV, could explain the difference between areas. However, the prevalence of such diseases is unlikely to differ much between adjacent areas such as the Petauke and the Katete Districts and the Chipata and Lundazi Districts and can thus not be the main reason for the observed differences in the effect of prevalence of trypanosomal infections on herd average PCV. Nutritional stress also may exacerbate the severity of trypanosomosis. However, livestock management practices do not differ between the different survey areas and none of the areas are, as yet, subject to overgrazing (RTTCP, 1999c). Furthermore, surveys were conducted during the rainy season when grazing is at its best. Hence, differences in nutritional stress are unlikely to be the reason for the observed differences in the relationship between prevalence of infection and herd average PCV. Field trials have shown that infection with one serodeme of trypanosome can induce immunity to reinfection with that particular serodeme but not to heterologous challenge. The immunity conferred, however, is short lived and is no longer apparent six months after the initial challenge (Murray and Urquhart, 1977). The development of such a "nonsterile immunity" to bovine trypanosomosis is difficult to assess but has been observed in areas of high challenge by a resident tsetse population that feeds mainly on cattle and where curative drugs are used to treat the acutely sick animals (Hornby, 1941; Boyt, 1967; Wilson *et al.*, 1976; Bourn and Scott, 1978). Such conditions do prevail in the Petauke District of eastern Zambia (Chapter 2 and Section 5.2.3) and may explain the observed difference in the relationship between the prevalence of infection and the herd average PCV in the Petauke District and in the other three districts. Indeed, herds in the Katete and Chipata Districts are subject to low and irregular challenge. This level of challenge may be insufficient for the development of protective immunity in cattle resulting in higher decrease in PCV for the same increase in prevalence compared to cattle in the Petauke area. Herds in the Lundazi District are subject to similar challenge as herds in Petauke District. However, because of the invasion of tsetse from the adjacent Lukusuzi and Kasungu National Park challenge is likely to be more heterologous and will not result in the same level of "nonsterile immunity" in cattle.

A major factor affecting the PCV is the plane of nutrition. Poor nutrition is known to result in a lower PCV (Sawadogo *et al.*, 1991; Katunguka-Rwakishaya *et al.*, 1995). A study, investigating the effect of season on the food intake of Angoni cattle in eastern Zambia, showed that poor pasture conditions and high temperatures cause nutritional stress during the dry but especially the hot dry season (De Clercq, 1997). Thus, the observed effect of season on the association between prevalence and herd average PCV is very likely to have been due to poor nutrition in the dry season. Whereas the season of sampling has no effect on the average PCV of the parasitologically negative herds, trypanosomosis seems to be less well tolerated during the dry season. This may explain the high proportion of trypanocidal drug treatments administered during the dry season (Section 5.2.3).

The above results indicate that the relationship between the prevalence of trypanosomal infections and the average PCV could be a useful tool in the management of trypanosomosis and planning of its control. Further research should be conducted in the temporal and spatial variations of this relationship and the factors affecting it.

4.3 An assessment of the impacts of bovine trypanosomosis on herd performance and offtake rates

4.3.1 Introduction

Bovine trypanosomosis occurs in vast areas of southern Africa (Connor, 1994). The distribution and prevalence of the disease is well established (Chapter 3). Its impact on cattle production, on the other hand, is less well known. Assessments of the socio-economic impact of the disease are, therefore, frequently based on assumptions. Nevertheless, the socio-economic impact of bovine trypanosomosis and the expected impact of its control are important criteria in determining the appropriateness of and need for a particular intervention.

The impact of bovine trypanosomosis on cattle production and marketing is best assessed by comparing various variables before and after the implementation of a control intervention in a particular area. This longitudinal approach is often difficult and time consuming. Alternatively, animal production and marketing can be compared between ecologically similar areas where cattle are either kept under tsetse challenge or where trypanosomosis is absent or has been controlled. This approach was adopted in collecting the results described in this section. To minimise the differences in cattle production variables and cattle marketing for reasons other than trypanosomosis, data were collected in a tsetse-infested and adjacent, ecologically similar, tsetse-free areas. Results were compared and the impact of bovine trypanosomosis was deduced.

4.3.2 Materials and methods

4.3.2.1 Survey areas

Surveys were conducted in six areas. In three areas (Petauke, Chipangali and Vwaza (adjacent to the game reserve,)), bovine trypanosomosis was prevalent. In the three other areas (Katete, Kasungu and Vwaza (>20 km from the edge of the game reserve) bovine trypanosomosis is virtually absent.

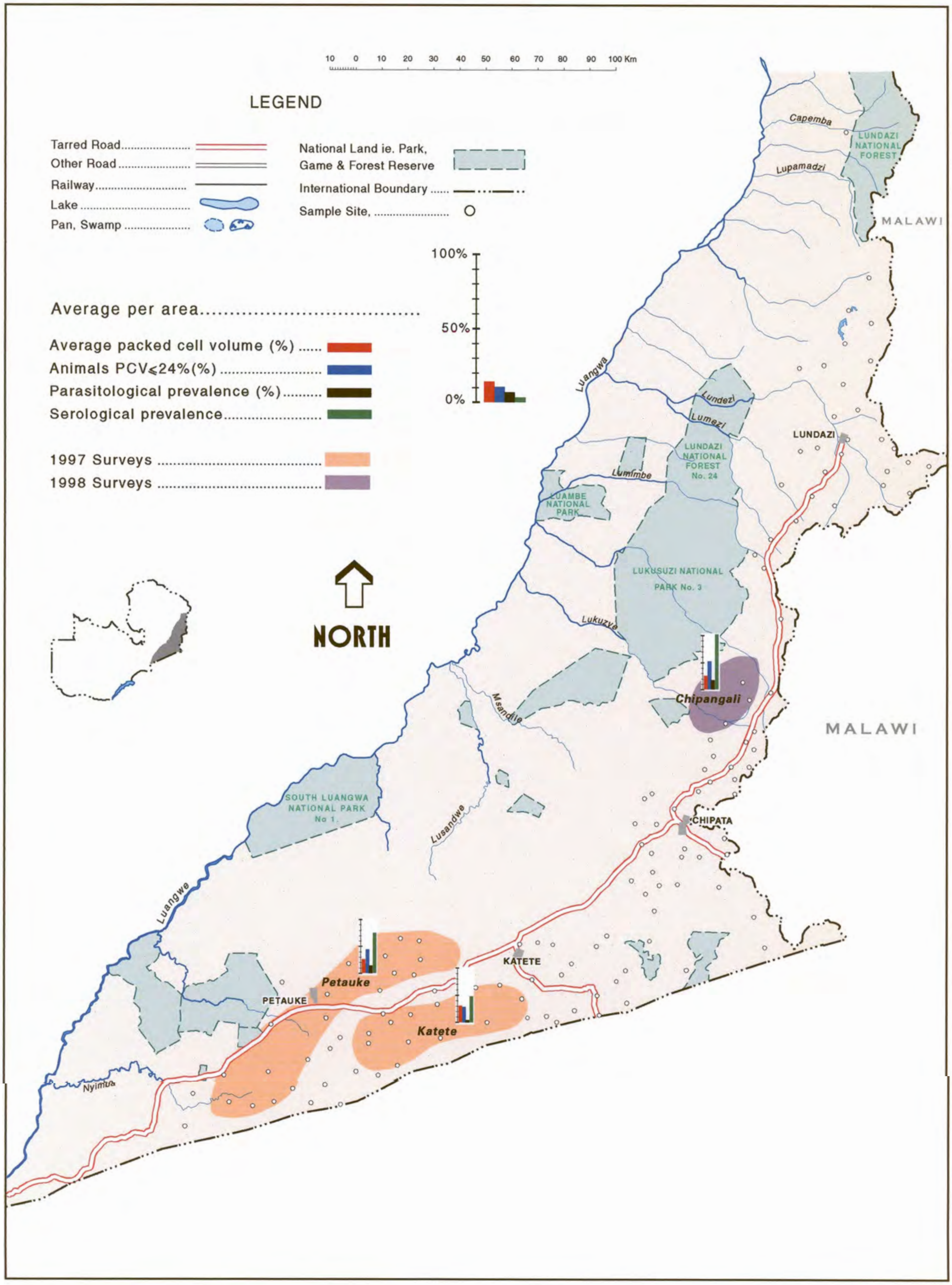
Petauke area

Baseline socio-economic surveys were conducted in an area of medium to high tsetse challenge (Petauke/Nyimba) of Petauke District in the Eastern Province of Zambia (Fig. 4.3.1) (Section 2.5.3.4). The area is situated on the eastern plateau and is part of the eastern tsetse-belt (Chapter 2). *Glossina m. morsitans* is the only tsetse species present and takes about 75% of its blood meals from cattle (Section 2.3.3). The monthly average incidence of bovine trypanosomosis is *ca.* 9% (Section 2.5.3.4). Trypanocidal drugs (diminazene aceturate and isometamidium chloride) are readily available. Trypanocides are used by the majority of the cattle owners (85%) (Section 5.2.3.1). In the use of trypanocides, preference is given to curative rather than prophylactic drugs. The majority of treatments are given to oxen and cows with each treated animal receiving *ca.* 1.5 treatments/year. The density of the trypanosusceptible Angoni breed cattle is on average 10 animals/km^2 but varies significantly between areas. Human density varies between 60-75 people/ km^2.

Katete area

A second survey was conducted in the tsetse-free Mvuvye/Katete South area of Katete District in eastern Zambia (Fig. 4.3.1). The area lies adjacent to the Petauke survey area. It is is ecologically similar and crops and crops combinations grown are virtually identical. Tsetse were controlled effectively using odour-baited, insecticide-treated, targets in the Mvuvye area and tsetse are absent in the Katete South area (Section 5.3.3). The area carries *ca.* 24 head of cattle/km^2. The human density is *ca.* 90 people/km^2.

Figure 4.3.1: Location of socio-economic survey areas in eastern Zambia



Chipangali area

The Chipangali area is located in the north-eastern corner of Chipata and the southern part of Lundazi Districts in the Eastern Province of Zambia (Fig. 4.3.1). To the north the area is bounded by the Lukusuzi National Park and to the east by the Kasungu National Park (Malawi). Both national parks are heavily infested with tsetse (*G. m. morsitans*). The Chipangali area is subject to tsetse invasion from both national parks (Wilson, 1975). The parasitological prevalence of bovine trypanosomosis is comparable to the prevalence in the Petauke area. Trypanocidal drug use practices are similar to the ones observed in the Petauke area (Section 5.2). Human and livestock densities are relatively low.

Vwaza area

The Vwaza survey area is located along the edge of the Vwaza Marsh Game Reserve in the Northern Region of Malawi (Fig. 3.4.3). The Vwaza Game Reserve is infested with tsetse (*G. m. morsitans* and *G. pallidipes*) (Davison, 1990). The survey was conducted within a band of *ca.* 40 km along the perimeter of the game reserve. Bovine trypanosomosis is present in herds located within 0-20 km from the edge of the game reserve (Vwaza < 20 km) (Section 3.4.3.4). The average prevalence of trypanosomal infections is about 7%. Bovine trypanosomosis is controlled with trypanocidal drugs by only 40% of the cattle owners (RTTCP, 1999b). Bovine trypanosomosis is absent between 20 to 40 km from the perimeter of the game reserve. Human population density in the Vwaza area is on average 85 people/km^2.

Kasungu area

The Kasungu survey area is situated along the edge of the Kasungu National Park in the Central Region of Malawi (Fig. 3.4.4). The Kasungu National Park is infested with tsetse (*G. m. morsitans*). A 6 km-wide barrier of odour-baited, insecticide-treated, targets (Section 3.4.4.2) prevents the spread of tsetse into the areas surrounding the eastern edge of the national park. Hence, the prevalence of bovine trypanosomosis is very low in the survey area (Section 3.4.4.2). The area is heavily settled, with a human population density of 104/km^2.

Because of spatial and temporal variations in the performance variables of cattle, comparisons between the trypanosomosis-infected areas could not be made. Therefore, the performance variables of each area where bovine trypanosomosis was prevalent were compared with those recorded in an adjacent ecologically similar trypanosomosis-free area (control area) surveyed during the same year (Table 4.3.1).

Table 4.3.1: Trypanosomosis-infected and their adjacent trypanosomosis-free (control) survey areas.

Survey areas		
Trypanosomosis-infected		Control
Petauke	⇔	Katete South
Chipangali	⇔	Kasungu
Vwaza (0-20 km)	⇔	Vwaza (>20 km)

4.3.2.2 Sampling methods

All surveys were conducted in the dry season between July/August and September/October. A rapid rural appraisal method was used (ILCA, 1990). Households interviewed were selected by using a two-stage cluster sampling method (ILCA, 1990). Detailed household counts were made for all the villages in each of the survey areas. Villages were then clustered, each cluster consisting of *ca.* 200 households. Twenty-five percent of the clusters were selected by random sampling and full household listings were made of all selected clusters. Households chosen for interview were selected by systematic sampling. Approximately 500 households were interviewed in each area.

A standard questionnaire was used (Annex 1). The questionnaire was pre-tested and revised to clarify specific questions and ensure that the average interview time did not exceed 45 minutes. Enumerators were trained for several days before the interviews were conducted. The questionnaire contained *ca.* 200 questions covering issues such as household characteristics, off-farm employment and income generation, crop and livestock practices and asset ownership. Replies were coded, transferred to a coding sheet and entered into a database. The Statistical Package for Social Sciences (SPSS, SPSS Inc.) was used to analyse the data.

4.3.2.3 Variables measured

The following variables were measured for the 12-month period prior to interview:

Mortality rates of different sex and age categories of cattle

- (Number of deaths/Total herd opening number for a sex or age category) x 100

Cattle performance

- Calving rate (%) = [(Calves born)/(Cow closing number + cow deaths + cow offtake – cow purchases)] x 100

  = (Calves born/Cow opening number) x 100

- Weaning rate (%) = [(Calves born - Calf deaths)/Cow opening x 100
- Offtake rate (%) = Total cattle offtake/total herd opening number x 100
- Sales rate (%) = Total cattle sales/total herd opening number x 100
- Commercial offtake rate (%) = Cattle sales + Exchanges/ total herd opening x 100

4.3.3 Results

The surveys were conducted between June 1997 and October 1998. A total of 2622 households were interviewed (Table 4.3.2).

Table 4.3.2: Number of households interviewed in each survey area.

	Survey area					
	Petauke	Chipangali	Vwaza <20km	Vwaza >20km	Katete	Kasungu
Households	546	424	277	255	541	579

4.3.3.1 Cattle ownership

The majority of the households in all survey areas did not own cattle (Table 4.3.3). The average proportion of households owning cattle in all survey areas was only 33.9%. Furthermore, average herd sizes per owner were small (Table 4.3.3). Cattle ownership was highly skewed with 5% and 10% of the households owning half of the cattle in the Malawian and Zambian survey areas, respectively. In all areas surveyed, the proportion of cattle owners lending cattle to relatives and other farmer was < 10%. Bovine trypanosomosis was reported as the main reason for cattle loss in the Petauke, Chipangali and Vwaza survey areas.

4.3.3.2 Herd structure

Herd structures differed substantially between survey areas. Herd structure in the Kasungu survey area was fairly typical for African sedentary farming systems in southern Africa where oxen constituting *ca.* 20% and cows between 30-35% of the average herd. In both tsetse-infested areas of Zambia the oxen/cow ratio was high (1.30 and 0.96 for the Petauke and Chipangali area, respectively). In the Vwaza area of Malawi, on the other hand, a very low ox/cow ratio was recorded (on average 0.38) (Table 4.3.4).

4.3.3.3 Cattle performance variables

Mortality rates

Except for the relatively high average mortality rates in the Petauke survey area, cattle mortality rates in all age and sex categories in the tsetse-infested areas were low (Table 4.3.5). Differences between the average mortality rates in the

Table 4.3.3: Frequency distribution of cattle ownership in each survey area.

Herd size	Survey area					
	Petauke[+]	Katete[°]	Chipangali[+]	Kasungu[°]	Vwaza[+]	Vwaza[°]
No cattle	69.3	51.4	66.7	71.2	83.0	78.8
1-5	12.0	24.7	15.6	14.3	8.3	10.9
6-10	11.6	11.1	9.0	7.4	4.5	7.3
11-15	3.6	6.2	4.0	3.8	1.8	2.4
>15	3.5	6.6	4.8	3.3	2.4	0.6
Average per owner	8.1	8.5	8.9	8.0	8.3	9.1

[+] trypanosomosis-infected areas
[°] control areas

Table 4.3.4: Proportion of cattle (%) in each age and sex category in each survey area.

Age and sex category	Survey area					
	Petauke^{+}	Katete^{o}	Chipangali^{+}	Kasungu^{o}	Vwaza^{+}	Vwaza^{o}
Male calves	6.6	9.7	5.7	8.3	9.2	10.1
Female calves	6.6	9.6	6.1	8.7	8.7	12.2
1-4 yr old males	6.8	11.0	9.8	8.3	11.4	7.1
1-4 yr old females	8.1	10.8	13.9	10.4	12.8	9.4
Cows	30.3	30.1	30.7	34.3	35.4	41.4
Oxen	39.3	25.6	29.4	24.8	14.9	14.3
Bulls	2.1	3.1	4.4	5.2	7.6	5.5

trypanosomosis-infected areas

^{o} control areas

Table 4.3.5: Average mortality rates (% ± 1 s.e.) per age and sex category of cattle in each survey area.

Age	Average mortality rate per survey area (%)					
category	Petauke$^+$	Katete$^\circ$	Chipangali$^+$	Kasungu$^\circ$	Vwaza$^+$	Vwaza$^\circ$
Cow	10.2 ± 2.2	10.3 ± 1.5	6.6 ± 1.7	4.7 ± 1.4	3.1 ± 1.9	3.7 ± 1.5
Oxen/bulls	8.4 ± 1.6	11.8 ± 1.8	4.6 ± 1.4	3.3 ± 1.2	2.3 ± 2.2	2.3 ± 1.5
Young stock	5.4 ± 1.7	3.6 ± 1.1	1.6 ± 1.2	8.1 ± 2.2	3.4 ± 3.4	17.5 ± 6.0
Calves	13.2 ± 2.1	8.7 ± 1.6	7.1 ± 2.8	8.4 ± 2.5	7.1 ± 2.6	8.1 ± 3.7

Table 4.3.6: Average calving and weaning rates (% ± 1 s.e.) per survey area.

	Survey area					
	Petauke$^+$	Katete$^\circ$	Chipangali$^+$	Kasungu$^\circ$	Vwaza$^+$	Vwaza$^\circ$
Calving rate	46.9 ± 4.6	47.8 ± 4.0	37.1 ± 4.0	49.2 ± 3.4	36.0 ± 3.2	53.7 ± 4.1
Weaning rate	40.7 ± 3.8	43.6 ± 3.5	34.4 ± 4.0	45.5 ± 3.5	33.5 ± 3.8	49.3 ± 3.7

$^+$ trypanosomosis-infected areas
$^\circ$ control areas

Petauke area and the adjacent Katete area were, however, not significant ($P>0.05$). were comparable to those recorded in their respective control areas (Table 4.3.5). Except for young stock, average mortality rates in the Chipangali and Vwaza (0-20 km) areas

Calving and weaning rates

With the exception of the Petauke survey area, average calving rates were significantly lower ($P<0.01$) in all trypanosomosis-infected areas compared to their control areas (Table 4.3.6).

4.3.3.4 Cattle sales, offtake rates and purchases

Mean sales rates and offtake rates were low in all areas (Table 4.3.7) and did not differ between cattle owners with small (less than the median number of animals) and large (above the median number of animals) herds ($P>0.05$). This suggests that the majority of cattle owners in tsetse-infested and tsetse-free areas meet cash needs by alternative means. In all areas, commercial reasons for disposal (sales and exchange) accounted for more than 50% of total offtake (Table 4.3.8). Emergency slaughter was particularly high in the Katete area (Table 4.3.8). This is attributed to an East Coast Fever (ECF, *Theileria parva*) outbreak a few months before the survey was conducted. Market-related reasons for not disposing of cattle (market prices too low, unable to sell cattle or not enough buyers) were relatively unimportant (Tables 4.3.9 and 4.3.10). They constituted less than 5% of all the reasons for not selling more animals.

In the year preceding the survey, a substantial proportion of households and cattle owners bought cattle in the Zambian survey areas (Table 4.3.11). The differences between the Zambian survey areas were not significant ($P>0.05$). In the Malawian survey areas, on the other hand, cattle purchases were substantially lower (Table 4.3.11). The cattle owners' strategies for stock purchase differed markedly between areas (Table 4.3.12). In the tsetse-infested areas in Zambia and most areas in Malawi, the majority of all purchases were draught animals. Most of the cattle (99%) were purchased from farmers living within the same area or a nearby village.

Table 4.3.7: Average gross offtake rate, sales rate and commercial offtake rate per cattle owner in each survey area.

Offtake measure	Survey area					
	Petauke$^+$	Katete^o	Chipangali$^+$	Kasungu^o	Vwaza$^+$	Vwaza^o
Gross offtake rate	7.0	7.9	9.0	13.7	19.4	17.9
Sales rate	3.7	3.5	2.6	5.3	8.1	6.5
Commercial offtake rate	3.9	3.7	3.9	5.8	8.6	9.5

Table 4.3.8: Frequency distribution of reasons for cattle disposal in each survey area.

Reason for disposal	Survey area					
	Petauke$^+$	Katete^o	Chipangali$^+$	Kasungu^o	Vwaza$^+$	Vwaza^o
Cash-sale	55.9	49.8	45.4	42.1	42.5	45.2
Home consumption	7.8	3.7	7.5	4.9	8.5	5.4
Lobola/bride price	5.0	2.3	20.1	26.2	8.5	15.0
Ceremonies	0	4.6	3.4	7.9	10.6	6.5
Emergency slaughter	15.6	25.6	9.2	11.0	23.6	19.3
Exchange	11.3	11.9	11.0	6.7	4.2	6.5
Other reasons	4.4	2.1	3.4	1.2	2.1	2.1

$^+$ trypanosomosis-infected areas

^{o} control areas

Table 4.3.9: Frequency distribution of reasons for not selling more cattle in each survey area.

Reason for not selling more cattle	Survey area					
	Petauke^{+}	Katete$^{\circ}$	Chipangali^{+}	Kasungu$^{\circ}$	Vwaza^{+}	Vwaza$^{\circ}$
No more cash required	22.4	30.8	26.5	36.0	43.5	51.9
Needed to keep oxen	43.3	33.7	25.8	13.4	8.7	1.9
Market prices too low	1.5	1.5	0	1.2	0	0
Not enough buyers	0	0	0	0	4.3	0
Herd too small	32.3	31.5	45.3	39.1	42.3	44.2
Other reasons	0.5	0.5	1.1	10.3	1.2	2.0

Table 4.3.10: Frequency distributions of reasons for cattle sale.

Reason for sale	Survey area					
	Petauke^{+}	Katete$^{\circ}$	Chipangali^{+}	Kasungu$^{\circ}$	Vwaza^{+}	Vwaza$^{\circ}$
Cash for specific purpose	85.6	82.6	100.0	91.6	87.5	88.6
Animals ready for market	4.8	2.7	0	2.8	3.1	0
Animals were sick	4.8	12.4	0	2.8	6.3	9.1
Other reasons	4.8	2.7	0	2.8	3.1	2.3

$^{+}$ trypanosomosis-infected areas

$^{\circ}$ control areas

Table 4.3.11: Proportion of households and owners buying cattle in each survey area.

Proportion buying (%)	Survey area					
	Petauke$^+$	Katete^o	Chipangali$^+$	Kasungu^o	Vwaza$^+$	Vwaza^o
Households	7.5	10.4	9.0	4.3	3.2	1.6
Owners	23.2	21.1	27.0	15.0	19.1	7.4

Table 4.3.12: Cattle purchases (%) within different stock categories per cattle owner in each survey area.

Stock purchase category	Survey area					
	Petauke$^+$	Katete^o	Chipangali$^+$	Kasungu^o	Vwaza$^+$	Vwaza^o
Males ≤ 4 yrs old	25.4	29.1	20.9	20.6	28.6	25.0
Males ≥ 4 yrs old	44.8	18.5	43.3	41.2	71.4	25.0
Females ≤ 4 yrs old	10.4	33.0	16.4	14.7	0	50.0
Females ≥ 4 yrs old	19.4	19.4	19.4	23.5	0	0

$^+$ trypanosomosis-infected areas
^{o} control areas

4.3.4 Discussion

4.3.4.1 Cattle ownership

In all survey areas the proportion of households owning cattle was low and ownership was highly skewed. Several studies in East and West Africa (Swallow, 1998) have indicated that the control of bovine trypanosomosis will lead to an increased proportion of households owning cattle with a concomitant increase in the average herd size per owner. Such an increase in cattle numbers after trypanosomosis control could be one reason for the higher proportion of households owning cattle and the larger average herd size in the Katete area compared to the adjacent, tsetse-infested, Petauke area of eastern Zambia. Increased cattle ownership and increased herd size should, however, not be considered as a normal consequence of trypanosomosis control. Indeed, notwithstanding the absence of trypanosomosis in the area 20-40 km from the edge of the Vwaza Game Reserve, the proportion of households owning cattle and the average herd size per owner does not differ significantly from the cattle ownership and average herd size in the area immediately adjacent to the game reserve where trypanosomosis is prevalent. In the Vwaza area, it is likely that the land pressure has placed severe limitations on the potential to increase herd size and cattle ownership.

Since wealth in terms of livestock ownership tends to be skewed towards the cattle owner (RTTCP, 1999b), trypanosomosis control interventions will tend to benefit the wealthiest part of the population most. Although difficult to quantify, trypanosomosis control will also have indirect effects on the non-cattle owners through, for example, increased availability of oxen for hire for land preparation. Therefore, an important indirect impact of trypanosomosis control is likely to be an expansion in the area ploughed per household with a concomitant reduction in the proportion of deficit food producing households (Swallow, 1998). However, the capacity to expand the cultivated areas depends on the amount of land available. The amount of land available is extremely limited in both Malawi survey areas with human population densities in excess of 100 people/km^2 around both game areas. In such circumstances the indirect impact on crop production will be limited.

4.3.4.2 Herd structure

Data on herd structures can be instructive. The observed variations between the different survey areas may reflect differences in management strategies or investment priorities that may result from particular constraints affecting the cattle owners. It is possible that some of the observed differences in herd structure are a result of the presence or absence of bovine trypanosomosis. The relatively high proportion of cows in herds in the tsetse-free area compared to both tsetse-infested areas of eastern Zambia, for example, could be the result of the farmers' emphasis on herd growth and the accumulation of breeding animals after trypanosomosis has been removed. Indeed, in areas where bovine trypanosomosis is endemic, the reproductive performance of cows is low with, consequently, low returns from investments in breeding stock (Section 1.4.1). This emphasis on oxen in tsetse-infested areas can clearly not be generalised suggesting that other factors, not related to the presence of tsetse, affect the herd structure. The low proportion of oxen in the Vwaza area of Malawi, for example, could again be a result of the low availability of arable land and small plot sizes, which reduces the need for draught power. Hence, the survey results indicate that it is dangerous to draw conclusions on the impact of bovine trypanosomosis, and its control, on herd structure.

Although the effect of nagana and its control on herd structure may be difficult to predict, knowledge of the existing herd structure is perhaps more important in the design of a strategy for the control of bovine trypanosomosis. The structure of the herd can, to a significant extent, determine the impact of trypanosomosis control on herd growth and, where land is available, the rate of arable land expansion. For example, in the Katete area, where herd structures are normal, herd size is likely to increase by *ca.* 3% per annum after trypanosomosis has been controlled (Doran, pers. comm.). In the Petauke area, on the other hand, where oxen constitute a large proportion of the herd (39.3%) annual herd growth will be substantially lower (0.9%) after trypanosomosis has been controlled.

4.3.4.3 Performance variables

The estimation of cattle performance parameters was an important objective of the survey. Parameter estimation is, however, fraught with problems since performance will be influenced by intra-and inter-seasonal climatic changes, disease outbreaks and levels of drug use, etc.

Mortality rate

Despite the presence of trypanosomosis, average mortality rates recorded in all Zambian survey areas fell within the ranges expected for communally kept cattle in Zambia (Perry *et al.*, 1984). In the Malawian survey areas also, average mortality rates were low (Soldan and Norman, 1994). The relatively high average mortality rates in most age and sex categories of stock in the Petauke and Katete areas were attributed to an outbreak of ECF during the February-June period preceding the survey. Swallow (1998), reviewing studies on the impact of trypanosomosis in various parts of Africa, stated that trypanosomosis increases calf mortalities by between 10-20% and reduces the density of cattle between 37-70%. Survey results collected in the trypanosomosis-infected areas in Zambia and Malawi cannot confirm those findings. The ranges of calf and adult mortality rates in the tsetse-infested areas of Zambia and Malawi were not atypical for traditional African livestock-keeping systems without trypanosomosis challenge and fell within the ranges recorded by Perry *et al.* (1984) (4-32% range and 4-10% range for calves and adults, respectively). A likely reason for the low mortality rate in all age categories of stock could be the effective treatment with trypanocides. However, trypanocidal drug use figures, collected in the survey area, indicate that the proportion of calves treated with trypanocides is low (Section 5.2.3.2). A more likely explanation for the low mortality in calves is, therefore, the low levels of tsetse challenge calves undergo. Research has shown the low attractiveness of calves to tsetse compared to adult animals (Torr, personal communication, 1999). This low level of attractiveness must result in a lower level of challenge and, hence, trypanosomosis-related mortality.

Calving and weaning rates

In two of the tsetse-infested areas, calving rates were significantly lower compared to their tsetse-free control areas. These results confirm observations made by other authors that trypanosomosis does affect the calving rate (reviewed by Swallow, 1998). Reproductive disorders are frequently seen in animals infected with trypanosomes (Section 1.4.1). They are attributed mainly to the effects of trypanosomosis on the endocrine system of cows resulting in irregular oestrus, foetal death and abortion (Ikede *et al.*, 1988; Gombe, 1989). The effect of trypanosomal infections on reproduction are reversible after diminazene aceturate treatment but it may take several months before normal cyclical activity resumes (Llewelyn *et al.*, 1988). It is, therefore, not surprising that the curative diminazene aceturate treatments administered by the cattle owners contribute little to improved reproductive performance in the tsetse-infested area.

The relatively high average calving rate in the Petauke survey area is more difficult to explain. Disease prevalence is comparable to the one in the Chipangali area and trypanocidal drug use practices do not differ (RTTCP, 1999c). However, a study investigating the effect of trypanosomal infections on herd average PCV showed that the effect was more severe in the Chipangali (Lundazi District) than in the Petauke survey area (Section 4.2.3). These results indicate differences in trypanosomosis tolerance between the two areas. In the Petauke area, the increased tolerance was attributed to the high level of homologous challenge by a resident tsetse population almost entirely feeding on cattle which induces a level of "nonsterile immunity" in the cattle population. Cattle in the Chipangali area, on the other hand, are subject to challenge by tsetse invading from the adjacent game areas (Lukusuzi National Park and the Kasungu Game Reserve). Since a substantial proportion of the invading flies obtained trypanosomal infections from game animals, cattle will undergo heterologous challenge and "nonsterile immunity" is unlikely develop. This may explain the lower tolerance of cattle to trypanosomosis in the Chipangali area (Section 4.2.3) and, hence, the low calving rate. Reasons for the low calving rate observed along the vicinity of the Vwaza Game Reserve are likely to be similar.

4.3.4.4 Offtake, sales rates and cattle purchases

In the context of planning for trypanosomosis control, it is important to obtain information about the sales and offtake rates and the reasons for cattle disposal. In all survey areas, sales rates were low and were influenced predominantly by the need to obtain cash to pay for food, school fees, clothes and inputs (*e.g.* drugs and/or fertiliser). Market-related factors (*e.g.* prices or animal condition) did not seem to constrain the offtake of cattle.

Sales and offtake rates are often assumed to increase after control operations become effective and benefits of this kind are sometimes incorporated in economic and financial appraisals of trypanosomosis control interventions. Swallow (1998), for example, stated that trypanosomosis control may result in a 30% increase in the commercial offtake of cattle. However, the direct relationship between cattle sales rates and cash needs observed in all survey areas has important implications. When, for example, alternative sources of cash are available these are likely to be used to meet cash needs in preference to the sale of cattle (Doran *et al.*, 1979; Low *et al.*, 1980). Significant improvements in, for example, crop revenue earning capacity thus tend to be associated with reduced sales rates and more rapid herd accumulation. Animal disease interventions, such as trypanosomosis control, which increase the availability of draught power and hence the capacity to expand the areas under cultivation are, therefore, likely to have similar effects on the rate of herd accumulation over time. Other things being equal, the greater the agricultural potential of an area and the greater the capacity for arable land expansion, the greater will be the capacity for herd accumulation and the lower the aggregate offtake and sales rates.

Survey results indicate that trypanosomosis control did not affect the proportion of households or cattle owners purchasing cattle. In the Zambian survey areas, however, the cattle purchase data suggest that, under tsetse challenge, emphasis is given to the purchase of especially adult males for draught purposes. Removal of the trypanosomosis constraint, appears to shift the emphasis to a longer term herd accumulation strategy in which the purchase of breeding females is given priority. As suggested above, the high proportion of male cattle purchased in tsetse-infested areas can be explained by the low reproductive performance of females. Other factors may also affect the purchase strategy.

The outcomes of the socio-economic surveys conducted in Zambia and Malawi indicate that is it is dangerous to make generalizations on the impact of bovine trypanosomosis and its control on cattle production and offtake. With the exception of the impact of the disease on calving rates, all other direct and indirect impacts are affected by non-trypanosomosis related factors such as the cattle owners' disease management practices, the potential for herd and arable land expansion and cash requirements. All these factors and their linkages and the local decision making process have to be considered when planning for the localised control of bovine trypanosomosis. Failure to do so may result in an overestimate of the benefits accruing from control and is likely to affect the sustainability of an intervention.

CHAPTER FIVE

OPTIONS FOR THE CONTROL OF BOVINE TRYPANOSOMOSIS

5.1 Introduction

Control of tsetse-transmitted trypanosomosis can be based on the control of the causal agent, the trypanosome, the control of the vector, the tsetse fly, the genetic selection of resistant cattle or a combination of all.

Despite the progress made in the development of effective tsetse control methods, trypanocidal drugs are, and will continue to be, an important means of controlling bovine trypanosomosis. In several countries of southern Africa (Malawi, Zambia and Mozambique), trypanocidal drugs (diminazene aceturate and isometamidium chloride) are readily available. The current and future effectiveness of a trypanosomosis control strategy based on the use of trypanocidal drugs will be determined largely by the prevalence of trypanosome strains resistant to those drugs. In areas where drug resistance is absent or present at low prevalence, the potential for widespread resistance in trypanosomes to these compounds is an important component determining the sustainability of a control strategy based on trypanocides. Detailed information on the distribution and prevalence of trypanocidal drug resistance in trypanosomes is not available. Moreover, tests to detect resistance are labour intensive, expensive and are unlikely to provide information on time or on a scale required for planning. The factors contributing to the development of resistance to trypanocidal drugs, on the other hand, are well-known (Section 1.5). Hence, detailed area-specific data on, for example, levels of trypanocidal drug use, trypanocidal drug preference, dose and frequency of application could be used as a practical, indirect indicator of the likelihood of the development of resistance to trypanocidal drugs in trypanosomes.

To determine current trypanocidal drug use in a bovine trypanosomosis endemic area and assess the potential for the development resistance a survey on trypanocidal drug use was conducted in eastern Zambia (Section 5.2). The survey results were used to determine the appropriateness of a bovine trypanosomosis control strategy based on trypanocides in the area. Moreover, general principles of cattle owners' attitudes towards trypanosomosis and its control were deduced and conclusions, relating to the implementation of other control methods were drawn (Section 5.2).

During the past 20 years much effort has gone into the development of low-technology and cost-effective tsetse control methods (Section 1.5). At the moment, most tsetse control operations rely on the use of stationary (odour-baited, insecticide-treated targets) or mobile (insecticide-treated cattle) baits. Odour-baited targets have been used to clear tsetse from large areas of Zimbabwe (Lovemore, 1999). They have proved to be highly effective when used in large areas where human and cattle population densities are often low. Moreover, odour-baited. insecticide-treated target barriers are highly effective in preventing the re-invasion of tsetse (Section 3.6.3) or significantly reducing the contaqct between tsetse and cattle at the edge of tsetse-infested areas (Section 3.4.3). Despite the successful implementation of the target technology under these conditions, the effectiveness of the method in controlling tsetse in small cultivated areas with high cattle and human population densities, where trypanosomosis is endemic and tsetse habitat patchy, still needs to be assessed. This situation occurs on the plateau area of eastern Zambia (Chapter 2). To evaluate the effectiveness of the target technology under the conditions prevailing on the plateau area of eastern Zambia, a tsetse control trial using odour-baited, insecticide-treated targets was conducted (Section 5.3).

Much of the development of insecticide-treated cattle as mobile baits to control tsetse has been conducted in southern Africa (Section 1.5). Nevertheless, with the exception of a few small trials, the method has never been used on a large-scale. Furthermore, the effectiveness of insecticide-treated cattle under the various epidemiological situations prevailing in southern Africa (Chapter 3) still needs to be assessed. It is, for example, important to clarify the effect of insecticide treatments on the tsetse's feeding responses and trypanosomosis transmission. Any repellent or irritant effect that the insecticide has on tsetse could be of particular importance in situations where the interaction between tsetse and cattle occurs along the edge of a tsetse-infested area (Section 3.4.3.4). Therefore, a trial was conducted to evaluate the effect of deltamethrin (the most commonly used pyrethroid to control tsetse) applied to cattle on the transmission of bovine trypanosomosis (Section 5.4). In view of the localised control of tsetse, effective barriers are required to prevent re-invasion. Targets effectively prevent tsetse re-invasion (Hargrove, 1993). However, the maintenance of a target barrier is costly and constant vigilance is required in order to prevent the barrier breaking down. Recent work has indicated that the efficacy of insecticide treatment of cattle against tsetse might be greater than was originally supposed (Baylis and Stevenson, 1998) and it has been suggested that cattle treatments alone might be sufficient to stem the re-invasion of tsetse. To assess the potential use of insecticide-treated cattle as a barrier to re-invasion of tsetse, a trial was conducted in northeastern Zimbabwe (Section 5.6).

Insecticide-treated cattle have lead to the clearance of mainly riverine species of tsetse from large areas in West Africa (Section 1.5.2.2.2). The effectiveness of the method in cultivated areas, where tsetse (savannah species) distribution is patchy still needs to be assessed. A trial was, therefore, initiated in eastern Zambia (Section 5.7).

Finally, the pyrethroid insecticides used to control tsetse have good acaricidal activity. Hence, regular treatment of cattle with pyrethroids is likely to have a significant effect on the tick population. This may affect the development and maintenance of enzootic stability to certain tick-borne diseases. To determine the effect of regular deltamethrin treatments on the epidemiology of babesiosis, a survey was undertaken in northeastern Zimbabwe (Section 5.5).

5.2 An analysis of trypanocidal drug use in the Eastern Province of Zambia

5.2.1 Introduction

In many parts of Africa where bovine trypanosomosis is a serious constraint to development, trypanocidal drug treatments constitute the principal method of controlling the disease. Despite the availability of effective vector control methods, it is very likely that in the foreseeable future, chemotherapy and chemoprophylaxis will continue to contribute significantly to the control of bovine trypanosomosis.
Only a small group of chemoprophylactic and chemotherapeutic compounds are currently in use and new compounds are unlikely to become available in the near future (Peregrine, 1994). Moreover, there is growing concern that the effectiveness of this control method will be severely reduced by the widespread development of resistance in trypanosomes to these compounds (Geerts and Holmes, 1998).

Notwithstanding the importance of this trypanosomosis control method and the threat of drug resistance, little is known of how African communal farmers use trypanocides. This is partly because of the decline in services offered by veterinary departments in many African countries, which has resulted in the unsupervised use of many veterinary drugs, including trypanocides.

Information on the use of trypanocides is required when determining options for the control of trypanosomosis in an area. Depending on the drug-use strategy, areas can be selected where chemoprophylaxis or chemotherapy may be an effective and sustainable way of controlling trypanosomosis. In other areas, information on trypanocides may indicate that they are not a viable option and other methods, such as vector control, should be adopted.

In the course of developing strategy options for the control of bovine trypanosomosis in Zambia, a survey was conducted to quantify and qualify the current use of trypanocidal drugs in the Eastern Province. Use was made of a rapid rural appraisal method. The survey aimed at determining the way that communal cattle owners use trypanocides. The value of this rapid rural appraisal approach is discussed.

5.2.2 Materials and methods

5.2.2.1 Survey area

A survey was conducted in Petauke District of the Eastern Province of Zambia in December 1997. Two areas were surveyed; Mvuvye (referred to as tsetse-controlled) and Petauke/Nyimba (referred to as tsetse-infested). They are situated on the eastern plateau and are ecologically similar with medium to high agricultural potential and mixed farming systems. *Glossina m. morsitans* was the only tsetse species present. The annual climatic cycle comprises three seasons; the rainy season (from November to April), the cold dry season (from May to August) and the hot dry season (from September to October). In the Mvuvye area (*ca.* 900 km^2), an odour-baited, insecticide-treated target, tsetse control operation was initiated in 1989 (Section 5.3). Despite the resulting decline in trypanosomosis prevalence, animals that graze outside the area may still contract trypanosomosis. The monthly average incidence of trypanosomal infections was 3.3% (mainly due to *T. congolense*) (Department of Animal Health and Production, unpublished data).

In the Petauke/Nyimba area (*ca.* 2000 km^2), tsetse are not controlled. The monthly average incidence of trypanosomal infections at the time of the survey, also mainly due to *T. congolense*, was *ca.* 10% (Section 2.5).

In both survey areas, farmers buy the trypanocidal drugs, diminazene aceturate (Berenil®, Hoechst, in sachet of 2.36 g) and isometamidium chloride (Samorin®, Rhône Mérieux, in sachet of 1 g), from the offices of the Department of Veterinary Services or from a Government Veterinary Assistant at cost. Widespread resistance of trypanosomes to either of the trypanocidal compounds used in the survey areas had not been reported at the time of the survey.

5.2.2.2 Sample selection and questionnaire

Cattle owners using trypanocides were identified during a socio-economic survey conducted in the same areas from June to September 1997 (Section 4.2). A total of 262 cattle owners indicated that they had purchased trypanocidal drugs during the year preceding the survey. Two hundred and seven of these trypanocidal drug users (101 in the tsetse-controlled and 106 in the tsetse-infested area) were interviewed in a more detailed follow-up survey to determine trypanocidal drug use practices. A uniform questionnaire was used (Annex 2). The questionnaire was pre-tested on a pilot basis. It was revised to clarify specific questions and ensure that the average time taken to interrogate each respondent was not more than 45 minutes. Enumerators were trained for several days before interviewing farmers. Questions were posed on herd structure, trypanocidal drug preference, treatment rationale, reason for treatment, method of treatment and treatment frequency. The information obtained was coded and entered into a database. Statistical analyses (chi-square tests) were conducted using the Statistical Package for Social Sciences (SPSS, SPSS Inc.) software.

5.2.3 Results

5.2.3.1 Drug purchase and drug administration

The majority of the cattle owners, in both survey areas, had used trypanocides during the year before interviews (Table 5.2.1). In each area, farmers preferred to use diminazene aceturate rather than isometamidium chloride (Table 5.2.1). Nevertheless, about 30% of trypanocide users used a combination of both drugs. The choice of drug did not differ between areas ($P>0.05$).

Table 5.2.1: Proportion of farmers owning cattle, proportion of cattle owners using trypanocidal drugs and drug preference in the two survey areas.

Survey area	Cattle - owners (%)	Cattle owners using trypanocides (%)	% trypanocide users using		
			diminazene aceturate	isometamidium chloride	both drugs
Tsetse-controlled	49.7	73.7	63	4	33
Tsetse-infested	30.1	85.1	68	5	27

Most of the trypanocidal drugs purchased (98.9%) were obtained from representatives of the Department of Veterinary Services. In the majority of cases (66.7%), cattle owners themselves administered the drugs. Only a small proportion of users (12.1%) indicated that veterinary personnel administered treatments. There was no difference between areas (P>0.05).

During the year preceding the survey, *ca.* 26% of the cattle owners in the tsetse-controlled and 15% of cattle owners in the tsetse-infested area used no trypanocidal drugs at all. The main reasons given (more than 90 % of the answers in both areas) were that "the animals were not sick and did not require treatment" or "the drugs were too expensive". Few cattle owners (less than 5 %) reported that they could not obtain the drugs.

5.2.3.2 Frequency of treatments and category of cattle treated

Application rates and the proportion of the herd treated with each trypanocide did not differ significantly between areas (P>0.05) and are thus not correlated with the disease challenge. Diminazene aceturate users treated, on average, 4.9 animals per herd (approximately 50% of the average total number of animals in the herd). Isometamidium chloride users treated, on average, 7.6 animals per herd (about two thirds of the average total number of animals in the herd). The proportion of oxen and cows receiving treatment with either drug was substantially higher compared to other classes of stock (Table 5.2.2). Irrespective of the type of drug and the age and sex category of stock, an average of *ca.* 1.5 treatments was given annually to each animal (Table 5.2.2).

5.2.3.3 Reason for trypanocide use

In both areas, the reasons for trypanocidal drug use were very similar (Table 5.2.3). More than 75% of the diminazene aceturate treatments were given to clinically sick animals (Table 5.2.3). However, only 15% and 13% of the diminazene aceturate treatments in the tsetse-controlled and tsetse-infested area, respectively, were given to animals with trypanosomal infections or suspected of having trypanosomal infections (Table 5.2.3). Only about 30% of all isometamidium chloride treatments, in both survey areas, were given to prevent trypanosomosis (Table 5.2.3). On the other hand, almost half of the isometamidium chloride treatments were for the reason that "animals were sick but the reason was unknown" (Table 5.2.3).

Table 5.2.2: Proportion of cattle treated with each trypanocide and average number of treatments by age and sex category (since proportion of cattle treatment and number treated did not differ between survey areas, data for both areas were pooled).

Category	Diminazene aceturate		Isometamidium chloride	
	% treated in each category	Treatments/animal/ year for those treated (± 1 s.e.)	% treated in each category	Treatments/animal/ year for those treated (± 1 s.e.)
Calves (0-1 year old)	2.5	2.00 ± 0.77	16.4	1.82 ± 0.48
Young stock (1-4years old)	22.2	1.22 ± 0.09	32.8	1.54 ± 0.26
Cows	55.1	1.40 ± 0.07	61.2	1.49 ± 0.17
Bulls	8.6	1.41 ± 0.27	23.9	1.69 ± 0.35
Oxen	83.8	1.52 ± 0.07	82.1	1.63 ± 0.23

Table 5.2.3: Reasons for diminazene aceturate and isometamidium chloride use in each of the survey areas.

Reason for use	Survey area Tsetse-controlled (%)		Tsetse-infested (%)	
	Diminazene	Isometamidium	Diminazene	Isometamidium
Trypanosomosis diagnosed	5.2	0	4.0	0
To prevent trypanosomosis	-	33.3	-	29.0
Trypanosomosis suspected	11.3	-	8.9	-
Animals sick (reason unknown)	63.9	47.2	66.3	48.4
Combination	17.5	5.6	9.9	9.7
Other reasons	2.1	13.9	10.9	12.9

5.2.3.4 Season of treatment

The majority of treatments were given during the dry season (Table 5.2.4). The seasonal pattern of treatment was almost identical for both areas.

Table 5.2.4: Proportion of treated animals receiving diminazene aceturate and isometamidium chloride during different seasons of the year.

Season of Treatment	% of drug users using	
	Diminazene aceturate	Isometamidium chloride
Wet Season	20.2	26.7
Dry Season	60.4	53.4
Both Seasons	19.4	19.9

5.2.3.5 Dosage rate and drug application

Evidence from the survey suggests that most of the farmers who used trypanocides did not under-dose with either diminazene aceturate or isometamidium chloride (Tables 5.2.5 and 5.2.6). On the contrary, at a normal dose rate of 3.5 mg diminazene aceturate/kg body weight and 0.5 mg isometamidium chloride/kg body weight, most calves and young stock in the 1-4 year age category were being overdosed (Table 5.2.5).

Only 17.4% of the trypanocide users indicated that they used boiled water to dilute the drug. Most of them (75%) diluted the trypanocides in water from potentially contaminated sources (dam, river, well or a combination of these). Sixty-seven percent

Table 5.2.5: Frequency distribution of the number of animals treated with 1.05 g of diminazene aceturate.

Number of animals treated	Category (in %)		
	Adult stock	Young stock (1-4 years old)	Calves (0-1 year old)
1	97.9	84.5	2.0
2	2.1	14.9	87.6
>2	0.0	0.6	10.4

Table 5.2.6: Frequency distribution of the number of animals treated with 1g of isometamidium chloride.

Number of animals treated	Category (in %)		
	Adult stock	Young stock (1-4 years old)	Calves (0-1 year old)
8	42.4	1.6	0.0
10	56.1	71.2	4.5
12	1.5	10.6	4.5
14	0.0	3.0	0.0
16	0.0	9.1	22.7
20	0.0	4.5	62.2
>20	0.0	0.0	6.1

of the users kept residual isometamidium chloride powder for later use. The remainder of the farmers (33%) sold the residual powder to other cattle owners.

5.2.4 Discussion

5.2.4.1 Drug purchase and drug administration

In all areas, preference was given to the use of a curative (diminazene aceturate) rather than a prophylactic drug (isometamidium chloride). Most trypanocides were obtained from representatives of the Department of Veterinary Services. This arrangement reduces the risk of administering generic products which may have unknown efficacy and offers a useful mechanism to monitor drug sales and drug application rates. Given the recent decline in the level of services offered by the veterinary department, cattle owners administer most trypanocides themselves. This may increase the risk of underdosing. However, survey results indicate that this does not seem to be the case. On the contrary, most of the calves and young stock receive an overdose of both drugs. The use of non-sterile water may induce the formation of abscesses that can reduce the availability of the drug. Advice is required to improve the mode of application

5.2.4.2 Trypanocidal drug-use strategy

In both areas, the majority of trypanocidal treatments are given to clinically sick animals that are not necessarily infected with trypanosomes. Moreover, irrespective of the type of trypanocidal drug used, oxen and cows received the majority of treatments. This suggests that farmers prefer to treat the productive animals in the herd and appear to apply a production-oriented curative treatment strategy. This may also be the reason why most treatments were given during the dry season when body condition and tolerance of infection are lowest (Doran, unpublished data).

Despite the differences in the monthly incidence of trypanosomosis between the two areas, the trypanocide-use tactics adopted are similar. This suggests that after the implementation of tsetse-control measures and the concomitant reduction of the challenge, cattle owners are unlikely to automatically change their pattern of trypanocide use. This is not surprising given the history of tsetse challenge before tsetse control and the treatment strategy, which focuses on the treatment of clinically sick animals rather than only on animals infected with trypanosomes. At the observed treatment frequency in the tsetse-controlled area, the number of trypanocide treatments given is higher than the monthly average incidence of trypanosomal infections (3.3%). Indeed, on the assumption that all animals infected with trypanosomes in the tsetse-controlled area were clinically sick and were treated, 68% of the diminazene aceturate treatments given to oxen (26% of treated herds) and 48% to cows (30.1% of treated herds) were inappropriate or administered to animals that were not infected with trypanosomes. In young stock (21.8% of treated herds), 46% of the diminazene treatments were given inappropriately. Obviously, the proportion of inappropriate treatments increases when isometamidium use is taken into consideration. Moreover, many animals infected with trypanosomes may not be clinically sick which will increase the number of inappropriate treatments even more. Since diagnostic facilities are not readily available, it will be difficult for the cattle owner to distinguish between clinically sick animals infected with trypanosomes and clinically sick animals infected with other disease agents. Cattle owners in the tsetse-controlled areas would, therefore, benefit from improved diagnosis and improved veterinary extension advisory services.

At the observed treatment frequency in the tsetse-infested area, on the other hand, 95% of the trypanosomal infections in oxen (39.3% of treated herds), 64% of the trypanosomal infections in cows (30.9% of treated herds) and 22% of the trypanosomal infections in young stock (14.9% of treated herds) could have been treated with diminazene aceturate. These figures will also increase when isometamidium treatments are taken into consideration. In the tsetse-infested area, a large proportion of the clinically sick animals is likely to be infected with trypanosomes often concealed by the presence of more readily detectable secondary infections (Connor, 1994b). Hence treatment of clinically sick animals in the trypanosomosis endemic area may, in the absence of microscopic diagnosis, be an effective way of combating trypanosomosis-related mortality. This seems to be the case since the cattle mortality rate in the tsetse-infested area did not differ from that in an adjacent tsetse-free area (Section 4.2). Moreover, the strategy of administering curative treatment to clinically sick animals in the tsetse-infested area is likely to keep oxen in reasonable condition during the ploughing season. Despite the substantial proportion of treatments given to cows, compared to other categories of cattle, many trypanosomal infections in cows were not treated. The treatment regime adopted would have boosted the condition of clinically sick cows but would not have improved their reproductive performance. Hence, the significantly lower calving rate recorded in the tsetse-infested area compared to that in the adjacent tsetse-free area (44.1% compared to 60.4%) (Doran, personal commication, 1999). Trypanosomosis is known to reduce reproductive performance of cattle (Losos and Ikede, 1972). There are, however, numerous examples of susceptible cattle being kept successfully under tsetse challenge. This may be achieved by applying strict treatment regimes with chemotherapeutic or, especially, chemoprophylactic drugs (Boyt, 1979; ILCA, 1988). A curative treatment strategy, as adapted in the tsetse-infested survey area, is not sufficient to maintain normal reproductive performance of cows.

5.2.4.3 Risk of development of trypanosome resistance

A major drawback, which affects the sustainability of chemotherapy in the control of bovine trypanosomosis, is the development of resistance by trypanosomes to trypanocides. Resistance to mainly chemoprophylactic trypanocides used in cattle has been reported at sites in West, Central, East and southern Africa (Peregrine, 1994). It is widely accepted that the best way to delay the development of drug resistance is to reduce selection pressure on parasite populations. This is best achieved by using the correct dose, decreasing the treatment frequency and reducing the number of animals treated (Geerts and Holmes, 1998). The survey results presented in this section show that, even though farmers administer most of the trypanocides themselves, there is no evidence of frequent under-dosing. On the assumption that all diminazene aceturate treatments in the tsetse-infested area were given appropriately, only about half (51%) of all trypanosomal infections in a herd were treated. The risk of trypanosomes developing resistance associated with the frequent and large-scale use of chemoprophylactic drugs in the tsetse-infested area is, therefore, minimal. Additionally, only a small proportion of owners use isometamidium chloride and treatment frequency is low (Tables 5.2.1 and 5.2.2). Hence, the risk of resistance developing in trypanosomes associated with the frequent and large-scale use of chemoprophylactic drugs is also minimal. Since the incidence of trypanosomosis is low in the tsetse-controlled areas, the risk of resistance to trypanocides developing in this area appears to be extremely low. Thus, information obtained from the survey indicates that the factors enhancing the development of resistance to trypanocides are not present in any of the areas surveyed.

There is a lack of reliable information on the prevalence of trypanocidal drug resistance in Africa. Despite the availability of highly sensitive drug resistance monitoring tools (Geerts and Holmes, 1998), systematic surveys are too expensive for countries where trypanosomosis is a problem. It is, therefore, very unlikely that in the foreseeable future reliable data on the true prevalence of drug resistance will become available from systematic surveys. In this respect, the results of this and similar farmer-based surveys could provide a useful baseline to indicate the likelihood of the development of resistance to trypanocides in an area. Such information could be used to focus more technically based approaches to map both the temporal and spatial distribution of trypanocidal drug resistance.

Information obtained from this survey clarified the pattern of trypanocidal drug use by communal cattle owners in a trypanosomosis endemic area of Zambia. The outcome of similar surveys, conducted in Malawi and Mozambique, shows a similar production-oriented, curative strategy (Doran, unpublished data). According to these survey results the use of trypanocides is an appropriate option for the control of bovine trypanosomosis in these areas. However, a more rational strategic use of chemoprophylactic drugs could improve the reproductive performance of cows.

Valuable data have been obtained on the frequency of treatment, method of application and disease management strategies that could form the baseline for monitoring drug resistance. Improving veterinary extension could reduce the inappropriate use of trypanocides in areas where tsetse have been controlled.

However, in the absence of practical, affordable and easy tests for the diagnosis of trypanosomosis a certain level of inappropriate usage appears to be unavoidable.

The type of information obtained from this survey is essential when developing strategy options for the control of bovine-trypanosomosis and similar approaches could be adopted for planning of animal disease control in general. Communal farmers' attitudes towards the control of cattle diseases and the manner in which they spend money on veterinary medicines should form the baseline from which an animal disease control strategy is developed. This approach is likely to improve the acceptability and, hence, sustainability of animal disease control in communal areas.

5.3 The control of *G. m. morsitans* (Diptera: Glossinidae) in a settled area in Petauke District (Eastern Province, Zambia) using odour-baited targets

5.3.1 Introduction

In much of Zambia, bovine trypanosomosis retards agricultural development. The disease transmitted by tsetse, *Glossina* spp., depresses every aspect of livestock production making it impractical to keep domestic animals in areas heavily infested by the flies. During the past decades several attempts, using both aerial and ground spraying, have been made to control tsetse in the Eastern Province (Evison and Kathuria, 1984). Most of these operations caused considerable reduction in fly population density, or removed flies completely from some areas. Unfortunately, due to financial constraints on the Department of Veterinary and Tsetse Control Services and the lack of effective means of preventing re-invasion, most of the former controlled areas have been reinfested with the flies.

The development of odour-baited targets as a low-technology method of controlling *G. m. morsitans* and *G. pallidipes* in Zimbabwe (Vale *et al.*, 1986), and the successful application of this method to control *G. m. centralis* in the Western Province of Zambia (Willemse, 1991), led to the trial described in this section. The objective of the trial was to investigate the efficacy of odour-baited targets to control *G. m. morsitans* in highly cultivated areas with patchy tsetse distribution and high cattle densities. At the same time, a methodology for use of odour-baited targets in such cultivated areas was developed.

5.3.2 Materials and methods

5.3.2.1 Trial area

The trial was conducted in 300 km^2 of the Chimpundu area in Petauke District. It is situated between the Great East Road in the north, the Mozambican border in the south, the Chikalawa Road in the west and the Sinda Road in the east (Fig. 5.3.1). The trial area lies southwest of the area described in Section 2.2.2.1. The main vegetation type was miombo (Section 2.2.2.1). Hills in the area carry extensive woodlands of *Brachystegia* spp. whereas *ca.* 70 % of the lowland (munga, Section 2.2.2.1) is cleared for cultivation (subsistence farming). The area carries about 8-10 head of cattle/km^2 together with goats, pigs and a few game animals, mainly small antelopes. The tsetse species present was *G. m. morsitans* which takes 75% of its blood meals from cattle at this locality (Section 2.3). There are three main seasons : the rainy (November to April), cold dry (May to August) and the hot dry (September to October) (Section 2.2).

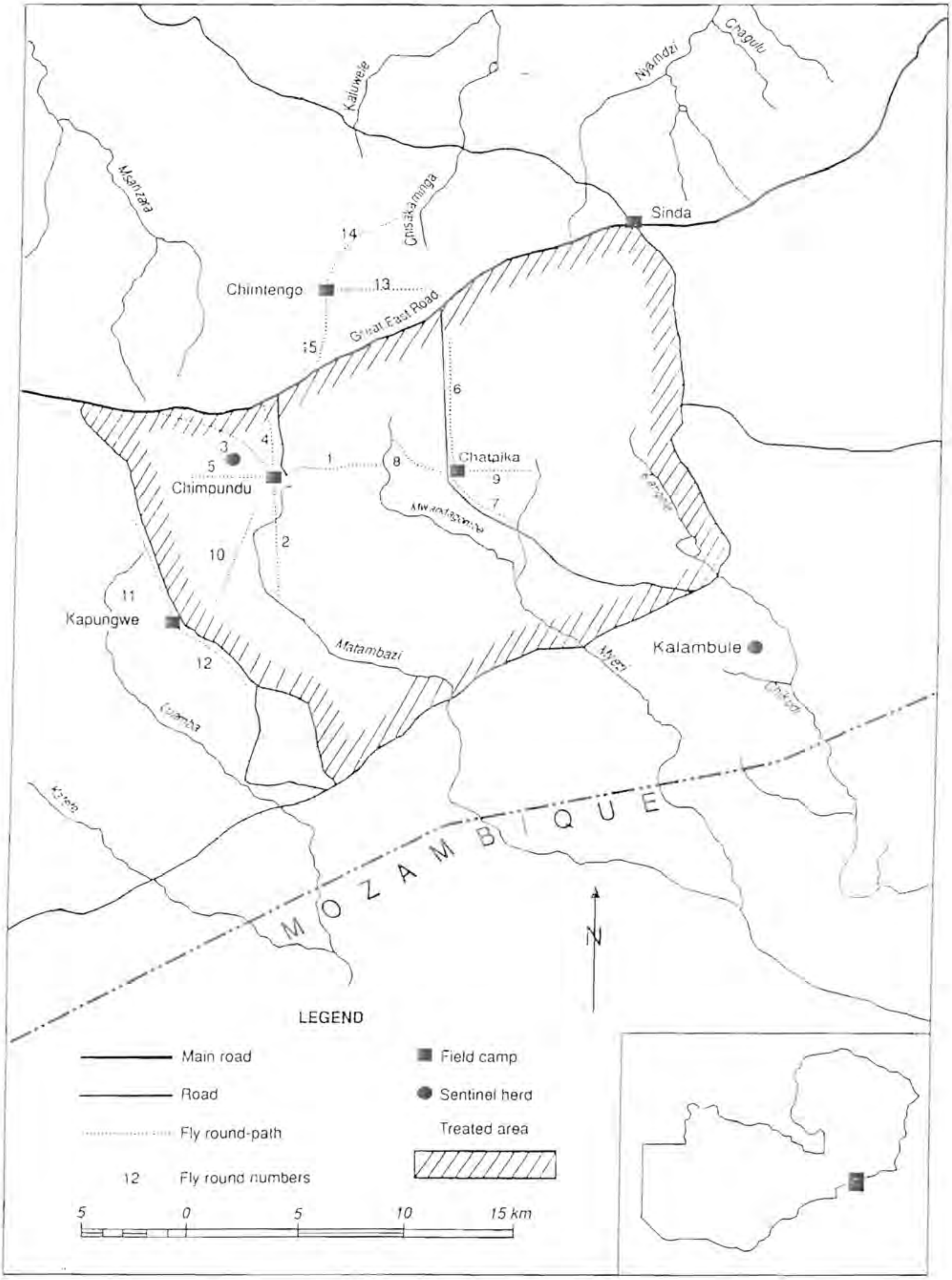
5.3.2.2 Targets

The S-type target (Vale *et al.*, 1988a), developed in Zimbabwe, was used in the trial. It consists of a central piece of black cotton cloth, 0.7 x 1.0 m, flanked on each side by fine black terylene netting, 0.5 x 1.0 m. Targets were fixed on a metal frame rotating in the wind about a central post.

5.3.2.3 Odour attractants

Acetone was dispensed from 500 ml brown glass bottles. Its vapour diffused through a 4.5 mm aperture in the lid resulting in an average dose of 250 mg/h. Bottles were placed in front of the target or attached to the top of its horizontal support; they were replenished at three-monthly intervals. For the first three months of the trial, 3-*n*-propylphenol/1-octen-3-ol/4-methylphenol (ratio of mixture: 1/4/8) in polyethylene sachet dispensers (150 μm thick, surface area 30 cm^2) were used as an additional odour attractant (Vale and Hall, 1985b). The sachet was placed in a pocket at the top of the central panel of the cloth.

Figure 5.3.1: Map of the trial area, fly round transects, location of field camps and sentinel herds.



5.3.2.4 Insecticide

All targets were treated with 0.1% deltamethrin (Glossinex 200 S.C.®, Coopers) applied by knapsack sprayers to both sides of the cloth and netting until run-off. Spraying intervals varied from two months during the rainy season to three months during the dry season. Eighteen months after the initial deployment, all targets were resprayed with 0.6% deltamethrin, and the spraying interval was increased to nine months. This significantly reduced the amount of maintenance work.

5.3.2.5 Target deployment

The targets were deployed mainly in miombo woodland. Patches of woodland, suitable for target deployment, were identified using 1/50 000 scale maps and 1/30 000 scale aerial photographs. Target deployment was facilitated by erecting most of the targets at 250 m intervals along roads. All equipment was transported using 4 WD vehicles and was hand-carried from the road to the selected deployment site. Each target site was identified by blazing trees along the roads. Teams, of 12 people each, deployed an average of 25 targets/day. The risk of targets being burned by bush fires was reduced by clearing all vegetation within 3 m of the target. All targets were numbered and mapped. A total of 980 targets were deployed during the cold dry season (July) giving an overall target density of 3.3 targets/km^2.

5.3.2.6 Target maintenance

Three permanent field camps within the trial area were used for maintenance operations (Fig. 5.3.1). Every working day, maintenance teams were sent to inspect and, if necessary, maintain targets. Torn, stolen, or faded cloths were replaced, odours were replenished and regenerating vegetation around the target was cleared. Extra casual labourers were employed for target resprays. To improve mobility, all labourers were issued with bicycles.

5.3.2.7 Monitoring of the tsetse population

The tsetse population was monitored along fly-round transects of *ca.* 6 km long with stops at 200 m intervals (Section 2.2.2.2). A total of 15 transects were traversed inside (transect number 1, 2, 3, 4, 5, 8 and 10), adjacent to (transect number 6, 7, 11, 12, 13 and 15), and outside the trial area (transect number 9 and 14) (Fig. 5.3.1). To produce sufficient pre-control data, tsetse monitoring started 18 months before the onset of the trial. The monthly average index of abundance (IA) of tsetse was calculated as the average number of flies (males and females) captured per stop and per fly-round. The monthly average indices of abundance in the trial area and adjacent area were expressed as a percentage of the monthly mean indices of abundance in the untreated area.

The corrected percentage was calculated using the following formula (Küpper *et al.*, 1982):

$$[\,[\,E_i \,.\, (C_m/C_i) - E_m\,] / [\,E_i \,.\, (C_m/C_i)\,]\,] \,.\, 100$$

where: E_i = Initial IA in the trial area

E_m = IA in the control area per month

C_i = Initial IA in the untreated area

C_m = IA in the untreated area per month

5.3.2.8 Trypanosomosis monitoring

To monitor the effect of tsetse control on the transmission of tsetse-transmitted trypanosomosis, the trypanosomosis incidence in cattle was assessed using two sentinel herds, one inside the trial area (Chimpundu) and one 5 km outside (Kalambule) (Fig. 5.3.1). Each herd consisted of 20 adult Ngoni breed cattle belonging to local farmers. The cattle were kept under traditional village management. Each month blood collected from each sentinel animal was examined using parasitological diagnostic methods (Section 3.3.2.2). Animals infected with trypanosomes received a curative treatment of diminazene aceturate (Berenil®, Hoechst), at a dose of 7mg/kg body weight for *T. brucei* or 3.5 mg/kg body weight for

T.congolense or *T.vivax*, by intramuscular injection. To evaluate the effect of the tsetse control measures on the prevalence of anti-trypanosomal antibodies, blood samples were taken from 20 adult and 20 young (6 -12 months old) head of cattle inside and outside the trial area 15 months after the start of the trial. Since the antibody-ELISA was not available at the time the trial was conducted, the anti-trypanosomal antibody levels were determined using the Immunofluorescent Antibody Test (IFAT) (Katende *et al.*, 1987).

5.3.3 Results

5.3.3.1 Index of abundance of tsetse

The monthly average IA of tsetse outside the trial area (Fig. 5.3.2) tended to be lowest in May/June (cold dry season) and highest a few months later (hot dry season). Allowing for this seasonal effect (Section 2.2.3.1), there was a fairly steady increase in the monthly average IA of tsetse over the four years of this study. The monthly average IA inside the trial area were, except for the 6 months before the onset of the trial, about the same as outside the trial area. After the targets were deployed the catches inside the trial area declined rapidly. One month after target deployment, tsetse catches in the trial area were 81.8% lower compared to catches outside the trial area (Fig. 5.3.3). A 94.8% reduction was reached three months later.

Except for four flies caught during the 1991 rainy season, no further fly catches were recorded.

A less drastic reduction in catches was observed on the area adjacent to the trial area. Here the monthly average IA declined by 38.4%, compared to catches outside the trial area, in the first month after target deployment. The monthly mean IA gradually decreased during the following months, reaching a maximum reduction of 97.6% eight months after target deployment (Fig. 5.3.3).

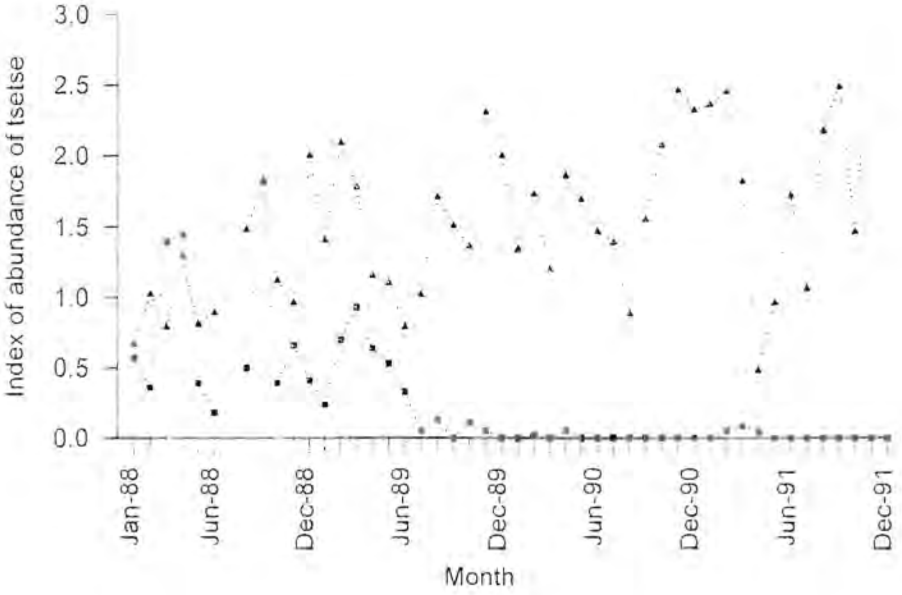


Figure 5.3.2: The monthly average index of abundance of *G. m. morsitans* inside (■) and outside (▲) the trial area.

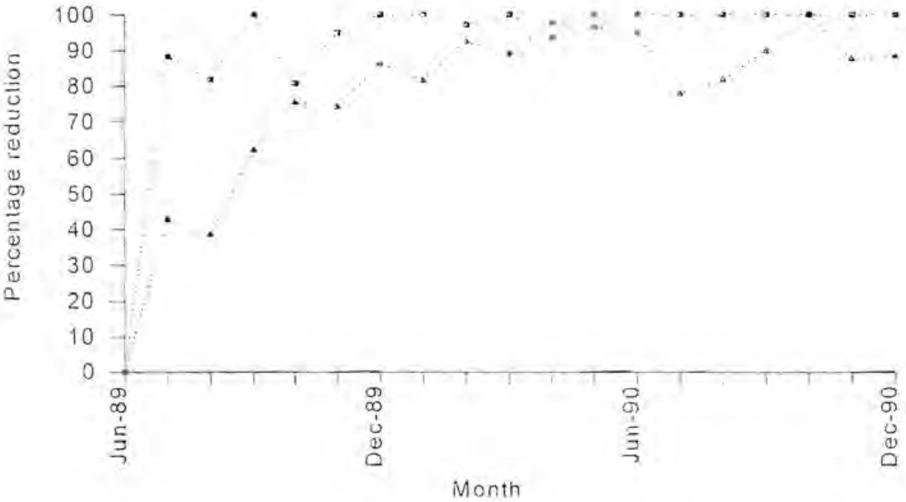


Figure 5.3.3: Reduction in the monthly average index of abundance of *G. m. morsitans* (%) inside (■) the trial area and adjacent (▲) to the trial area compared to catches outside the trial area.

5.3.3.2 Incidence of bovine trypanosomosis

Except for September 1990, trypanosomosis incidence was higher in the sentinel herd outside the trial area than in the herd inside the trial area (Fig. 5.3.4). None of the sentinel cattle were parasitologically positive in February 1990, June 1991, October1991 and December 1991.

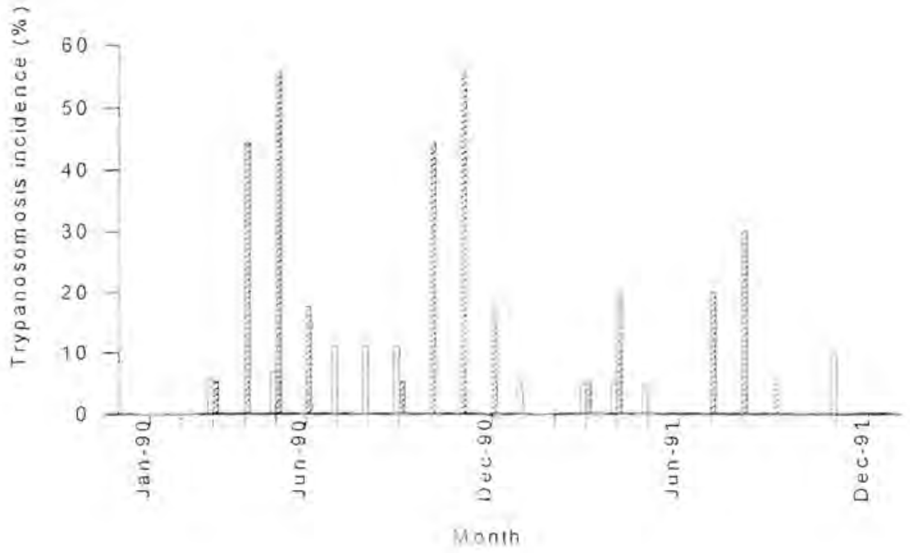


Figure 5.3.4: Monthly incidence of trypanosomal infections (%) in sentinel cattle inside (□) and outside (=) the trial area.

Inside the trial area, the incidence of trypanosomosis in sentinel cattle decreased significantly from an annual mean of 35.7% prior to target deployment to means of 5.4% and 2.3% in 1990 and 1991, respectively. However, outside the trial area trypanosomosis incidence remained high (Table 5.3.1). *Trypanosoma congolense* accounted for 96.1% of all infections.

Table 5.3.1: Annual average parasitological incidence of trypanosomal infections and average PCV in sentinel cattle inside and outside the target trial area and anti-trypanosomal antibody prevalence in adult and young cattle, 15 months after the start of the trial.

Location	Year	Average parasitological incidence (%)	Average PCV (%) (± 1 s.e.)	Antibody Prevalence (%) 15 months after trial start	
		Sentinel herds		Adults	Young
Inside	1990	5.4 ± 4.9	29.3 ± 3.5	88.9	20
	1991	2.3 ± 1.4	27.9 ± 4.0	-	-
Outside	1990	30.7 ± 21.5	25.6 ± 4.7	100	47.9
	1991	13.3 ± 11.7	25.2 ± 3.5	-	-

Differences between mean annual PCVs of sentinel herds kept inside or outside the tsetse-controlled area were statistically significant (P<0.01). Fifteen months after the start of the trial, 88.9% of the adult cattle sampled in the trial area had anti-trypanosomal antibodies. However, the prevalence of anti-trypanosomal antibodies in young animals kept in the tsetse-controlled area was substantially lower that the prevalence of anti-trypanosomal antibodies in animals of the same age-category but grazing outside the trial area (Table 5.3.1).

5.3.4 Discussion

The results of the trial indicate that odour-baited targets are very effective in controlling *G. m. morsitans*, under the conditions prevailing in the Eastern Province of Zambia. Compared to other areas where odour-baited targets have been used to control *G. morsitans* (Vale *et al.*, 1988; Willemse, 1991), the distribution of tsetse in the trial area is patchy and the contact between tsetse and cattle is high (Chapter 2).

The methodology used in this trial differs from that applied in other tsetse control campaigns using odour-baited targets (Vale *et al.*, 1988; Willemse, 1991). Due to the high level of cultivation and the subsequent patchy distribution of tsetse habitat, targets were not deployed along gridlines but deployment was restricted to suspected tsetse habitat. This resulted in an irregular distribution with concentration of targets in miombo and an overall target density lower than the recommended four targets/km^2 (Vale *et al.*, 1988). The deployment of targets along roads greatly facilitated their deployment and maintenance. Though it was beyond the scope of this trial, it is expected that access to targets could be an important parameter when the responsibility for target maintenance is ultimately handed over to the local community. As was observed by Vale *et al.* (1988) population density of *G. m. morsitans* was reduced for several kilometres outside the trial area. This effect is attributed to the movement of tsetse into the target-treated zone.

The decline of the tsetse population density was associated with a significant reduction in the incidence of bovine trypanosomosis and a significant increase in the average PCVs of cattle grazing in the trial area. This is not surprising in view of the highly significant regression between the index of abundance of tsetse and the incidence of bovine trypanosomosis (Fig 2.5.5). The PCV is a reliable indicator of anaemia (Saror, 1979), which is a major characteristic of bovine trypanosomosis (Murray and Dexter, 1988). Significant differences between herd PCVs could, therefore, be used as an additional indicator of trypanosomal infections and tsetse challenge. It is not surprising that the serological prevalence of trypanosomosis in adult cattle was high for 15 months after targets were deployed. The decline of anti-trypanosomal antibody levels is slow evan after challenge is reduced (Section 3.2.3), hence the high proportion of adult cattle with anti-trypanosomal antibodies inside the trial area. The prevalence of anti-trypanosomal antibodies in calves born in the trial area after the onset of the trial, on the other hand, was about 50% lower than in the control area. This clearly indicates a significant decrease in trypanosome challenge in the trial area. The sero-monitoring of young animals, born after tsetse have supposedly been cleared, could be a useful additional monitoring tool of a tsetse control campaign (Section 3.6.4).

From six months after the start of the trial, almost no tsetse were captured in the trial area. Trypanosomes were, however, still detected, though at a much lower incidence rate. There may be many reasons for this. The difficulty in detecting low density populations of *G. m. morsitans* and the limited area covered by fly-rounds hinders objective interpretation of entomological results. Moreover, tsetse eradication in the whole trial area could not be guaranteed because of the invasion pressure from surrounding areas. Hargrove (1993) suggested that an 8 km-wide barrier, with four targets/km^2, is needed to prevent re-invasion. This means that, in the case of this trial, only the most central part of the target area could be considered to have been re-invasion pressure free. Moreover, movements of sentinel cattle into tsetse-infested areas outside the trial block complicates interpretation of the incidence of trypanosomosis.

Expanding the treated area, creating a central area where tsetse are likely to be eradicated, could solve the problem of tsetse re-invasion. However, even this might not solve the problem of cattle moving to tsetse-infested areas, which can occur during the dry season when they search for grazing. Trypanosomosis incidence is determined by various host and vector-related parameters (Rogers, 1988; see Chapter 1). Theoretical disease transmission thresholds and basic rates of reproduction emphasise the difficulty of controlling trypanosomosis caused by *T. vivax* or *T. congolense* by any strategy other than total elimination of the vector (Rogers, 1988). Results of this trial and the epidemiological considerations indicate the importance of the scale at which such vector-control operations should be conducted.

Due to the rapidly growing human population, increasing number of people will have to settle in or near tsetse-infested habitats. Tsetse-transmitted trypanosomosis is expected to be a serious constraint to rural development for those communities. Results of this trial show that odour-baited targets can be used to control tsetse in such settled areas. It should, however, be realised that trypanosomosis control will only be achieved through large-scale vector control resulting in almost complete absence of challenge.

5.4 The effect of deltamethrin pour-on (Spoton®, Coopers) applied to cattle on the transmission of bovine trypanosomosis

5.4.1 Introduction

Tsetse flies (*Glossina* spp.), and the disease that they transmit, have been controlled successfully by applying insecticide to cattle or to artificial baits, termed targets (Bauer *et al.*, 1995; Green, 1994; Mérot *et al.*, 1984) (Section 5.3). With both types of application the disease transmission is reduced due to a slow decline of tsetse population densities in the surrounding areas, and hence a gradual reduction in challenge. However, there is some evidence that disease transmission can also be reduced more directly and immediately by the inhibition of the flies' feeding responses on insecticide-treated animals (Van den Bossche *et al.*, 1987; Bauer *et al.*, 1992a). Other evidence contradicts this (Thomson, 1987; Baylis *et al.*, 1994; Gouteux *et al.*, 1996).

It is necessary to clarify the importance of this direct effect of insecticide treatments on the tsetse's feeding responses or trypanosome transmission because it is the one which could offer an immediate benefit to the farmer who treats his cattle, irrespective of whether the cattle are treated in adjacent areas or irrespective of its effect on the tsetse population density (Echessah *et al.*, 1996). In contrast, the effect that depends on the decline of tsetse population density cannot be achieved by one farmer alone. If cattle in nearby areas are untreated, or treated only sporadically, the flies will persist there, allowing a steady stream of flies to invade the areas where cattle may be treated properly. In this case, deltamethrin treatments on cattle will have less effect on the incidence of trypanosomosis in treated cattle. A related problem occurs where cattle are kept immediately adjacent to a game reserve from which tsetse can continuously invade (Section 3.4.3).

The present work elucidated the importance of the direct effect by studying the incidence of trypanosomosis in groups of deltamethrin-treated and untreated cattle herded in the same area and subject to a similar and constant tsetse challenge.

5.4.2 Materials and methods

5.4.2.1 Trial area

The trial was conducted between August 1992 and December 1992 in the Katete District, Eastern Province, Zambia (31°50' E -13°05'S) (Section 2.2.2.1).

5.4.2.2 Experimental animals and treatments

Twenty-seven randomly selected adult oxen (Ngoni breed), aged between 1.5 and 3 years, were divided into two herds: a control herd (n = 15) and one treated with deltamethrin pour-on (Spoton®, Coopers) (n = 12). At the start of the trial (Week 0), all animals were eartagged and treated with diminazene aceturate (Berenil®, Hoechst) at 7.0 mg/kg body weight. Deltamethrin pour-on (Spoton®, 1% deltamethrin a.i.) was applied to all animals of the treated herd in a line along each side of the animal at a dose of 10 ml/100 kg body weight, using a T-shaped hand applicator. Pour-on treatment was repeated at 4-week intervals (Weeks 0, 8, 12 and 16).

To avoid the risk of contamination, oxen treated with deltamethrin pour-on were kept as one group and kraaled together. All animals were exposed to the same natural field challenge of tsetse by herding them in the same area (*ca.* 10 km^2). Different herdsmen looked after the treated and the untreated groups and kept the two herds separate.

To allow for a prophylactic effect of a double dose of diminazene aceturate (7mg/kg), all animals were considered to be protected during the first four weeks after the initial treatment. Trypanosomosis incidence in both herds was calculated at two-weekly intervals from Week 5 onwards. On each occasion, ear vein blood of all animals was examined for trypanosomes using the haematocrit centrifugation technique and the PCV was measured (Section 3.3.2.2). Since resistance to diminazene aceturate has not been reported in the trial area, trypanosomal infections were treated with diminazene aceturate at a dose of 7mg/kg body weight for *T. brucei* or 3.5 mg/kg body weight for *T.congolense* or *T.vivax*. Animals given diminazene were considered to be protected during the subsequent two weeks and were therefore excluded from the next calculation of incidence.

5.4.2.3 Statistical analysis

Packed cell volumes of treated and untreated cattle were compared using a t-test (Sokal and Rohlf, 1998). A one-sided Fisher's exact test (Sokal and Rohlf, 1998) was used to test whether the trypanosomosis incidence in the deltamethrin-treated herd was significantly lower compared to the incidence in the untreated herd (SPSS, SPSS Inc.).

5.4.2.4 Monitoring of tsetse population

The index of abundance of tsetse in each herd's grazing area was monitored using five epsilon traps baited with acetone (at a release rate of 200 mg/h) (Hargrove and Langley, 1990). Traps were sited in munga and miombo (Section 2.2.2.1). In addition, five epsilon traps (control traps) were deployed 10 km south of the grazing area. Trap cages were emptied daily. Live flies were dissected to determine trypanosome infection rate (Lloyd and Johnson, 1924). The monthly mean index of abundance (IA) of tsetse was calculated as the average number of flies (males and females) captured per day and per trap.

5.4.3 Results

5.4.3.1 Index of abundance of tsetse

The IA in the grazing area was similar to the IA outside the grazing area (Fig. 5.4.1). This is not surprising considering the low number of deltamethrin-treated cattle in the trial area.

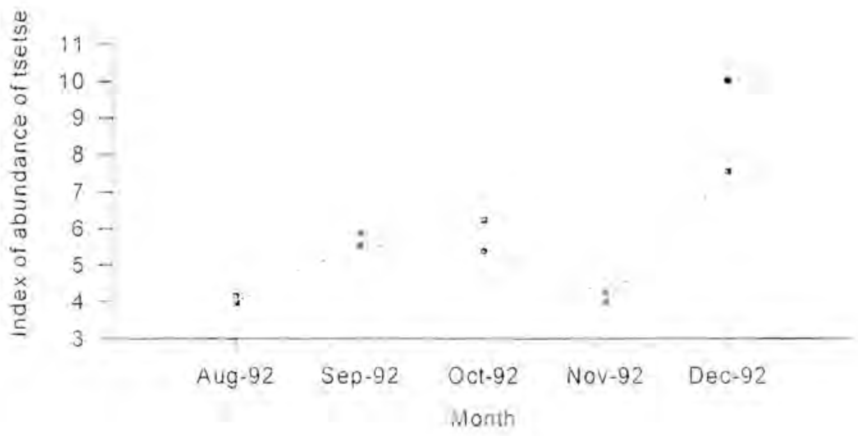


Figure 5.4.1: Monthly average index of abundance of *G. m. morsitans* inside the grazing area (■) and in the control area (◆).

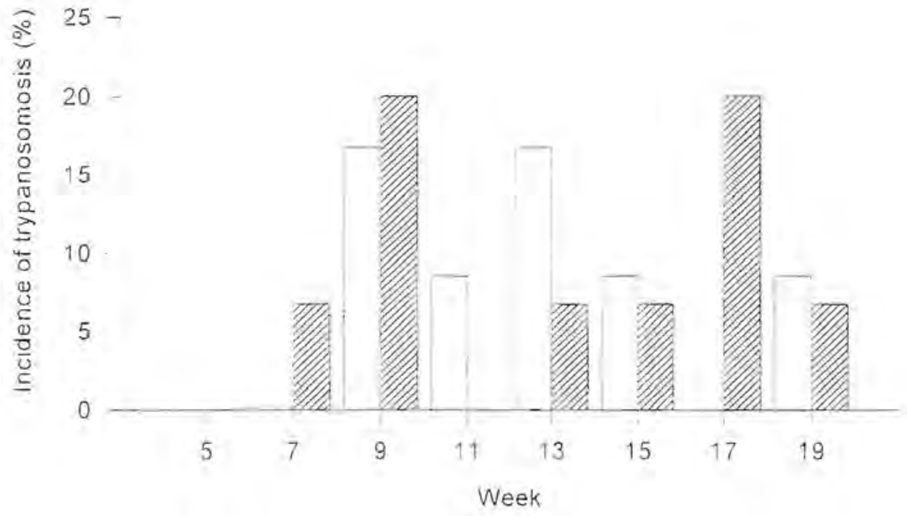


Figure 5.4.2: Two-weekly incidence of trypanosomosis in control (▨) and deltamethrin-treated (□) herd.

During the trial period, the monthly proportion of infected tsetse increased gradually from 0.63% to 2.5%. A total of 62.5% of the trypanosomal infections in tsetse were *congolense*-type, the remaining being *vivax*-type.

5.4.3.2 Incidence of bovine trypanosomosis

The first trypanosmal infection was detected seven weeks after the onset of the trial (Fig. 5.4.2). No trypanosomal infections were detected in Week 11 in the control herd and Weeks 7 and 17 in the deltamethrin-treated herd. Trypanosomosis incidence varied considerably between herds and between weeks. The average two-weekly trypanosomosis incidence, however, was 8.1% and 7.8% for the control and the deltamethrin-treated herd, respectively. A total of 16 trypanosomal infections were detected. *Trypanosoma congolense* accounted for the majority (87.5%) of the infections. The remaining 12.5% was attributed to *T. vivax*. The probabilities for the null hypothesis of no difference between the trypanosomosis incidence in the deltamethrin-treated and the untreated herds area is shown in Table 5.4.1.

Table 5.4.1: Two-weekly incidence of trypanosomal infections in deltamethrin-treated and untreated, control, herd and significance of Fisher' exact test.

Week	Control herd		Deltamethrin-treated herd		P-value
	Infected	Not infected	Infected	Not infected	
7	1	14	0	12	1.00
9	2	12	2	10	0.64
11	0	13	1	9	0.44
13	1	14	2	9	0.38
15	1	13	1	10	0.70
17	3	11	0	11	1.00
19	1	11	1	11	0.76

For none of the weeks was the difference between the incidence of trypanosomal infections significant.

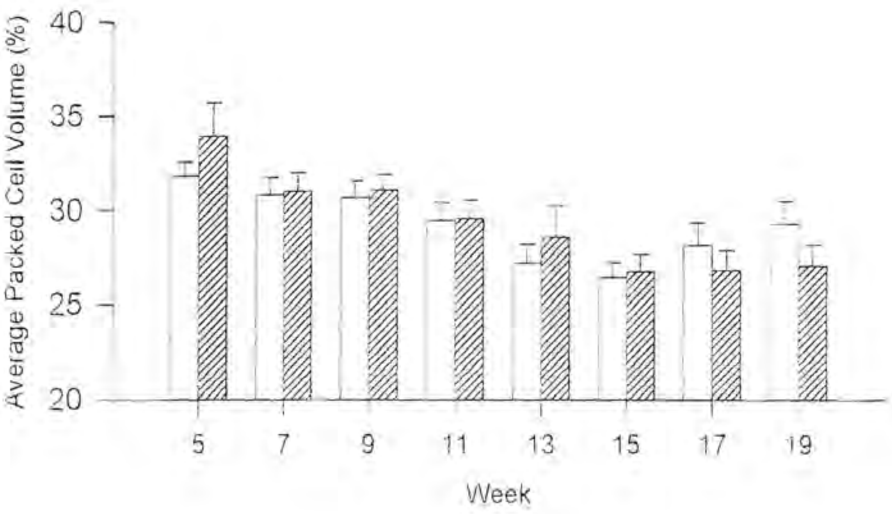


Figure 5.4.3: Two-weekly average packed cell volume (PCV) (+ 1 s.e.) of the control (□) and deltamethrin-treated (▨) animals.

The two-weekly average PCVs of both herds decreased gradually, from 32.8% in Week 5, to 26.6% in Week 15. From Week 17 onwards the average PCV increased, reaching 28.2% in Week 19. None of the differences between average PCV of untreated and deltamethrin-treated herds was statistically significant ($P>0.05$) (Fig. 5.4.3).

5.4.4 Discussion

During the three-month observation period, the incidence of tsetse-transmitted trypanosomosis was never statistically lower in the deltamethrin-treated herd compared to the untreated herd. This lack of association between deltamethrin treatments and disease incidence and the variations in the incidence of trypanosomosis between herds and between samplings could have been due to the low sensitivity of the parasitological diagnostic methods to detect trypanosomal infections (Paris *et al.*, 1982). Such low sensitivity could lead to the misclassification of non-diseased animals and consequently affect parasitological incidence. This low diagnostic sensitivity is, however, non-discriminatory and would have affected both the deltamethrin-treated and untreated herd. Therefore, it cannot affect the degree of association (Thrusfield, 1986). It can, nevertheless, cause substantial variations in the parasitological incidence of trypanosomosis between herds and between consecutive samplings.

Measuring indirect effects of trypanosomosis in both herds could partly compensate for the low diagnostic sensitivity. A major characteristic of bovine trypanosomosis is anaemia (Murray and Dexter, 1988) and the PCV is a reliable indicators of anaemia (Saror, 1979). Significant differences between herd PCVs could, therefore, be used as an additional indicator of trypanosomal infections and tsetse challenge. No significant differences were observed between the average two-weekly PCVs of the deltamethrin-treated and untreated herds. The gradual decrease in the PCV during the first 15 weeks of the trial followed by an increase during the last four weeks is attributed to seasonal changes in the pasture condition (Sawadogo *et al.*, 1991).

According to the parasitological incidence and PCVs, there was no difference between the incidence of tsetse-transmitted trypanosomosis in deltamethrin-treated and untreated herds.

A repellent or irritant effect of the deltamethrin pour-on, applied at the dose rate and treatment interval used in this trial, cannot be excluded from the current experimental design. This could affect the preference of tsetse for either treated or untreated animals Nonetheless, results indicate that even if such effects do occur, they are too small to reduce the trypanosomosis incidence to a level that would be a direct benefit accruing to the owners of treated animals.

Consequently, the effect of deltamethrin-treatment of cattle on the incidence of tsetse-transmitted trypanosomosis observed in other experiments or control campaigns seems to be a result of its effect on the population density of tsetse or tsetse challenge rather than its direct effect on the tsetse's feeding response. Successful control of tsetse-transmitted trypanosomosis using deltamethrin-treated cattle (at a dose rate of 10 ml Spoton®/100 kg body weight and at monthly treatment intervals) will, therefore, depend on the level of induced tsetse mortality and tsetse invasion pressure. The use of this tsetse control method in areas where, for whatever reason, the tsetse population density cannot be sufficiently reduced to reduce disease challenge will not result in a decline in trypanosomosis incidence.

5.5 The effect of short-interval deltamethrin applications to control tsetse, on the seroprevalence of babesiosis in cattle

5.5.1 Introduction

Regular treatments with acaricides have long been regarded as the most effective means of controlling ticks and tick borne-diseases. However, considerable evidence from several epidemiological studies has demonstrated that such intensive dipping has often been the main cause of tick-borne disease problems (Norval, 1983). As a result, most tick-borne diseases are nowadays managed by integrating the strategic use of acaricides, the application of vaccines if available and the exploitation of endemic stability if present.

The concept of endemic stability is well established. An endemically stable situation is one in which the majority of the host population acquires protective immunity to a particular tick-borne disease, through infection when young while still protected by passively-acquired and non-specific factors (Norval, 1983). For endemic stability to develop, infected vectors must be present in sufficient numbers to ensure regular challenge of young animals. Effective tick control, in areas where endemic stability is present, may cause endemic instability due to infrequent disease transmission. Consequently, animals will become susceptible and when challenged would develop clinical disease.

Regular treatments of cattle with pyrethroids, to control tsetse, might have a significant effect on the density of the tick population. The degree of tick control will, however, depend upon the interval between treatments, the proportion of animals treated, the acaricidal activity of the compound and the dose at which the pyrethroid is applied.

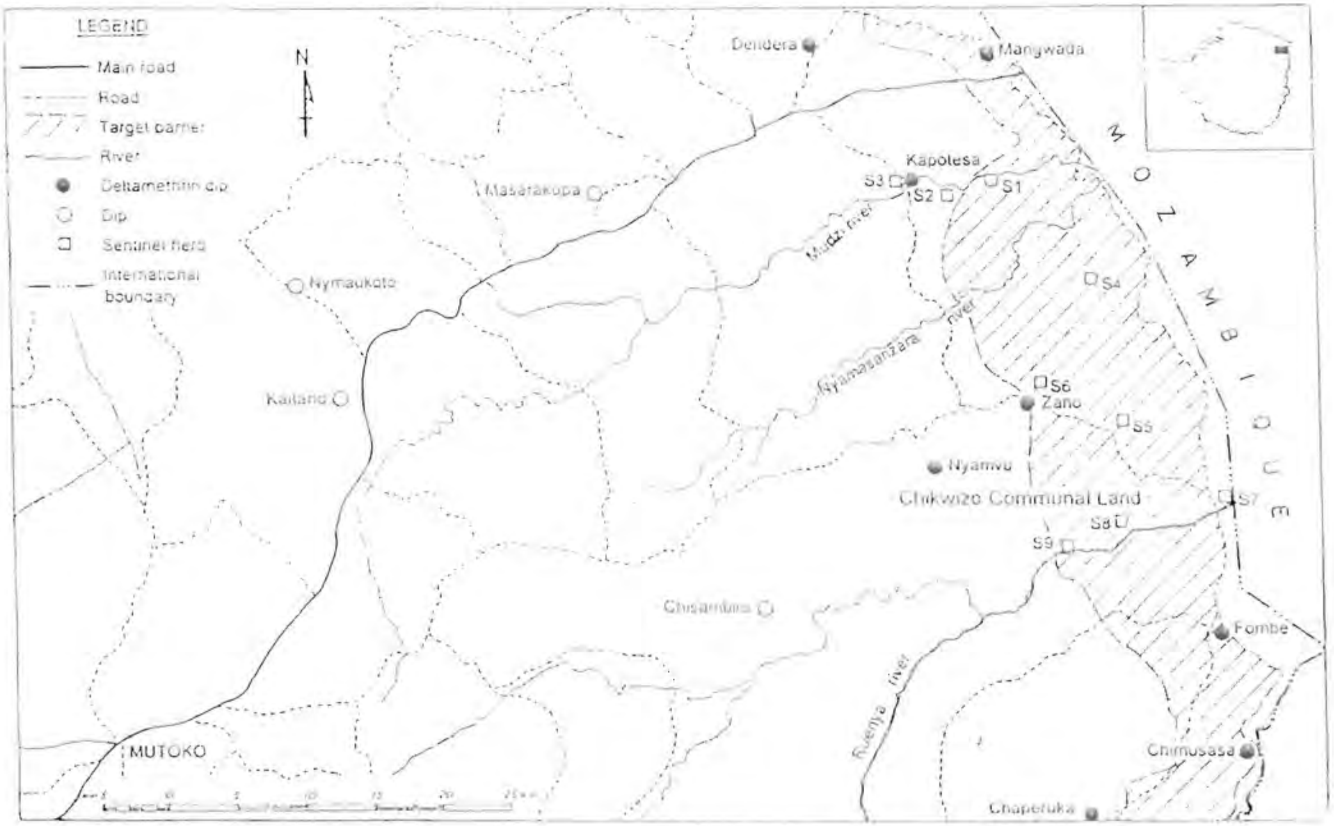
For the past decade, deltamethrin treatment of cattle along Zimbabwe's eastern/north-eastern border has been part of an integrated approach to counteract continuous invasion of tsetse from the Mozambique fly-belt (Shereni, 1990). To determine the effect of these deltamethrin treatments on the epidemiology of babesiosis, a survey was conducted to estimate the prevalence of antibodies against *Babesia bigemina* in adult cattle. The seroprevalence figures were compared with those from a survey conducted before the implementation of the tsetse control measures (Norval *et al.*,1983). The seroprevalence of *B. bigemina* in adjacent areas, where cattle are not treated with deltamethrin, was also determined for comparison.

5.5.2 Materials and methods

5.5.2.1 Trial area

The survey was conducted between November 1995 and February 1997 in the Chikwizo Communal Land (Mudzi District, Mashonaland East Province) (Fig. 5.5.1). The survey area had been cleared of tsetse for many years but is subject to continuous invasion of tsetse flies (*G. pallidipes* and *G. m. morsitans*) from the Mozambique fly-belt (Shereni, 1990; Van den Bossche and Mudenge, 1997; see Section 5.6). To protect tsetse-free areas, a barrier of odour-baited targets (Hargrove, 1993) was erected along the Mozambique border. From 1986 onwards, the effect of the target barrier was supplemented by compulsory treatments of cattle in a zone of 10-15 km wide (deltamethrin treatment zone, DTZ) (Fig. 5.5.1) by dipping them in 0.00375% deltamethrin (Decatix®, Coopers) at two-weekly intervals (Thomson and Wilson,1992). In areas adjacent to the DTZ (Fig. 5.5.1), cattle were treated with short residual acaricides (Amitraz, Triatix®, Coopers). *Babesia bigemina* is widespread in cattle in communal areas of Zimbabwe (Norval *et al.*,1983); the survey was, therefore, restricted to establishing its prevalence. The effect of regular deltamethrin treatments on the prevalence of *B. bigemina* was determined by comparing the serological prevalence of *B. bigemina* in the DTZ with its serological prevalence in cattle outside but adjacent to this zone.

Figure 5.5.1: Map of the trial area indicating location of the sentinel herds and the areas covered by the survey.



5.5.2.2 Sample collection and analyses

Jugular blood was collected from at least 30, randomly selected, adult communal cattle at 8 localities inside and 4 localities outside the DTZ (Fig.5.5.1). Serum was separated from the clotted blood and stored at –20°C prior to serological testing. The indirect fluorescent antibody test was used to detect anti-*B. bigemina* antibodies (Norval *et al.*, 1983).

To determine the level of *B. bigemina* transmission, 90 head of adult sentinel cattle were introduced into the DTZ in January 1996. Before introduction, all the animals were tested for antibodies to *B. bigemina*. Only serologically negative animals were retained and assigned to nine sentinel herds (S1-S9) (Fig. 5.5.1). Sentinel animals were not treated with deltamethrin. The prevalence of anti-*B. bigemina* antibodies in the sentinel cattle was determined at 3-monthly intervals.

Estimates of the monthly coverage with deltamethrin-treatments were obtained by comparing the number of animals dipped in a particular month with the total number of animals registered at that dip in the same month. The monthly average dipping coverage in the DTZ, expressed as a percentage of the total cattle population registered, was calculated for 1996.

5.5.3 Results

5.5.3.1 Proportion of cattle dipped

The proportion of animals dipped each month in the DTZ varied between 50 and 80% of the total population registered (Fig. 5.5.2). Attendance for dipping was lowest during the hot dry season and at the beginning of the rainy season.

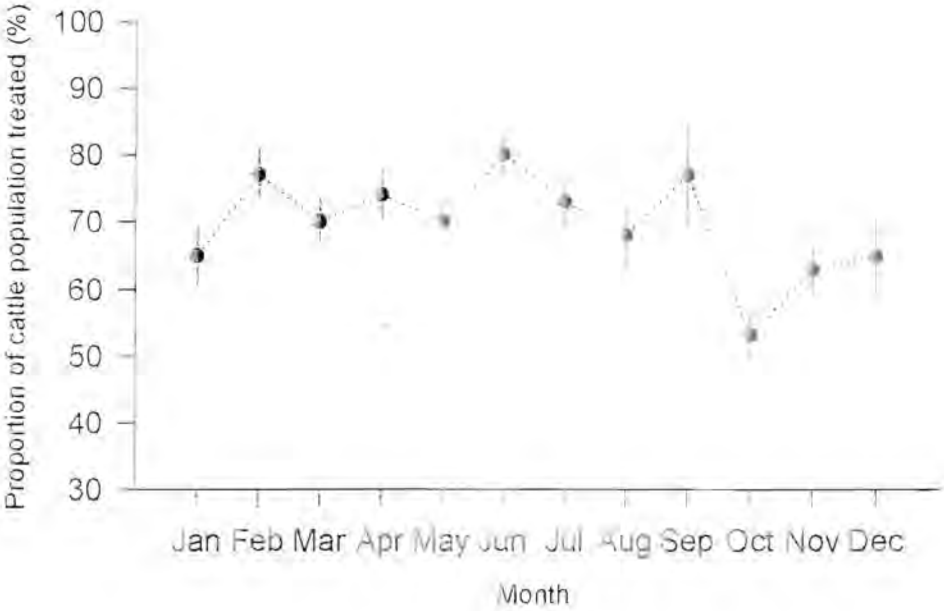


Figure 5.5.2: Monthly average proportion (± 1 s.e.) of the total cattle population treated in the "deltamethrin treatment zone" during 1996.

*5.5.3.2 Prevalence and incidence of cattle with anti-*B. bigemina *antibodies*

Anti-*B. bigemina* antibodies were detected in sera from cattle sampled at only two locations (25%) in the deltamethrin-treated zone. At those locations, the prevalence of serologically positive cattle was low, indicating low levels of disease transmission (Table 5.5.1).

Table 5.5.1: Prevalence of antibodies against *B. bigemina* in cattle sampled at various locations in the deltamethrin-treatment zone.

Location	Sample size	Number positive	Prevalence (%)
Zano	34	0	0
Nyamvu	35	0	0
Kapotesa	35	4	11.4
Mangwada	35	0	0
Dendera	35	0	0
Fombe	35	0	0
Chimusasa	33	0	0
Chaperuka	35	2	5.7

Serologically positive animals were present at all locations outside the DTZ (Table 5.5.2). The mean prevalence of antibodies against *B. bigemina* in cattle sampled at locations inside and outside the DTZ was 2.1 ± 1.5% and 43.2 ± 3.6%, respectively.

Table 5.5.2: Prevalence of cattle with antibodies against *B. bigemina* sampled at various locations outside the deltamethrin-treatment zone.

Location	Sample size	Number positive	Prevalence (%)
Masarakupa	30	13	43.3
Kaitano	43	20	46.0
Nyamukoto	63	32	50.0
Chisambiro	30	10	33.3

The proportion of sentinel cattle exhibiting antibody titres against *B. bigemina* varied between months (Table 5.5.3). However, incidence was generally low and did not increase in time.

Table 5.5.3: Variations in the proportion of sentinel cattle with antibodies against *B. bigemina* in the deltamethrin-treatment zone.

Month	Sample size	Number positive	Prevalence (%)
February '96	80	4	5.0
May '96	74	13	17.6
August '96	90	4	4.4
October '96	76	4	5.3
December '96	95	10	10.5
February '97	69	3	4.3
April '97	82	6	7.3

5.5.4 Discussion

A survey, conducted in 1980-81, on the prevalence of antibodies to *B. bigemina* and the distribution of ticks of the genus *Boophilus* in Zimbabwe revealed that *B. bigemina*, together with its main vector *Boophilus decoloratus*, occurred throughout the country (Norval *et al.*,1983; Mason and Norval, 1980). In most areas where dipping was non-existent or irregular, the prevalence of antibodies against *B. bigemina* was high, suggesting that endemic stability was present. Unfortunately, the 1980-81 survey did not cover the area in this study. The above results showed that the prevalence of antibodies to *B. bigemina* was much higher in areas where dipping with a non-pyrethroid acaricide was conducted than in the DTZ. Seroprevalence is, however, insufficient to assume endemic stability for *B. bigemina* (Norval *et al.*, 1983).

The compulsory dipping of cattle in deltamethrin to control tsetse appears to have been very successful in also controlling *Boophilus* spp. The relatively low prevalence of *B. bigemina* antibodies in the 90 susceptible adult animals at risk of natural infection in the DTZ (Table 5.5.3) confirmed that the challenge of *Boophilus* spp. in that area was low. This low population density of *Boophilus* spp. reduced the chance of cattle receiving an immunizing infection as young animals when they would have been relatively resistant and may have acquired protective immunity. The spread of infected ticks to such susceptible populations of cattle or the introduction of susceptible cattle to endemic areas could lead to serious disease outbreaks (Lawrence *et al.*, 1980).

Both deltamethrin and amitraz have good acaricidal activity when applied at two-weekly intervals (Norval *et al.*, 1992; Fox *et al.*, 1993; Chizyuka and Luguru, 1986). This is certainly the case for one-host ticks such as *Boophilus* spp. The better control of *Boophilus* spp. in the DTZ is attributed to the regular use of deltamethrin to control tsetse and the stringent supervision of dipping practices by Government services. This resulted in a high coverage of the animals and, consequently, good tick control (Fig. 5.5.2). In the adjacent zone in which amitraz was used, on the other hand, dipping was often disrupted due to problems with water or acaricide supply. As a result, tick control was less rigorous and permited the development of endemic stability.

The dose of deltamethrin required to control tsetse is far below that required to control ticks. Therefore, the most obvious solution to avoid potential adverse effects of severely reducing the population of ticks would be to extend the interval between deltamethrin treatments. Although a certain degree of tick control is unavoidable, pyrethroids used to control tsetse should be applied at intervals or doses that give optimal tsetse control without affecting the transmission of tick-borne disease agents and, hence, permit the development of endemic stability. The intervals, varying from 1 to 3 months depending on the insecticide and its formulation, at which pyrethroid insecticides should be applied to control tsetse have been derived from laboratory studies (Bauer *et al.*, 1992a; 1989; 1988) and have been adopted in the field. At such extended treatment intervals no immediate effect on tick-borne disease transmission is expected. Nevertheless, the long-term effect of such treatments on tick populations is still unknown. If, for whatever reason, the intervals between treatments used to control tsetse need to be shortened, adverse effects on the tick population and transmission of tick-borne diseases are to be expected.

The results of this survey clearly demonstrate the importance of an integrated approach towards disease control. Potential adverse effects of pyrethroid treatments used to control tsetse on the transmission of tick-borne disease should be taken into consideration at the onset of tsetse control operations.

5.6 Evaluation of insecticide-treated cattle as a barrier to re-invasion of tsetse to cleared areas in northeastern Zimbabwe

5.6.1 Introduction

In Zimbabwe over recent years, a combination of tsetse control methods has successfully eradicated the fly from large parts of the country's interior, leaving infestations in the northeastern Zambezi Valley and along the eastern border with Mozambique (Shereni, 1990; Lovemore, 1999). As a result, a large proportion of the tsetse control budget in Zimbabwe (20%) is now spent on maintaining the barriers to tsetse re-invasion from neighbouring countries (Shereni, 1990). These barriers consist of odour-baited, insecticide-treated, targets in a band, 8 km wide, at an operational density of 4/km^2 (Hargrove, 1993). Such barriers are supported by the compulsory treatment of all cattle adjacent to the barrier with the synthetic pyrethroid deltamethrin, either as a dipwash (Decatix®, Coopers) at two-weekly intervals, or as a pour-on (Spoton®, Coopers) at monthly intervals.

The maintenance of a target barrier is costly. Target service intervals are usually shorter in target barriers due to the increased theft problems associated with the semipermanent layout of the targets, and constant vigilance is required in order to prevent the barrier breaking down. The treatment of cattle with deltamethrin pour-on or dip is also more costly than the acaricide that is routinely used for tick control in Zimbabwe, further increasing the cost of maintaining the barrier.

Recent work has suggested that the efficacy of insecticide treatment of cattle against tsetse might be greater than was originally supposed (see Bauer *et al.*, 1992b, 1995; Fox *et al.*, 1993) and it has been suggested that cattle treatments alone might be sufficient to stem the re-invasion of tsetse into cleared areas of Zimbabwe. If this were case, a considerable cost saving could be made.

This section reports the results of a field trial which was undertaken to see if insecticide-treatments of local cattle alone could act as a barrier to the re-invasion of tsetse into cleared areas of Zimbabwe.

5.6.2 Materials and methods

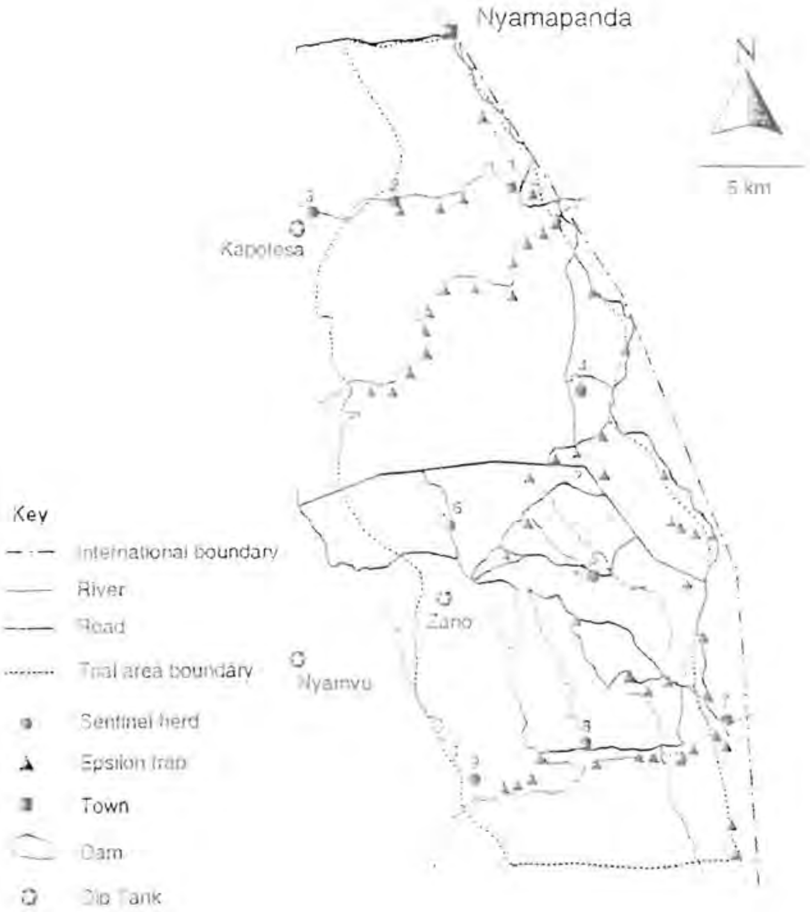
5.6.2.1 The trial area

An area of 428km^2 ($\approx$40 km long and 5-15 km wide) adjacent to the Mozambique border and to the south of the Tete road in northeast Zimbabwe, was chosen for the trial (Fig. 5.6.1). Archive data showed that this area suffered a high invasion pressure from populations of both *G. m. morsitans* and *G. pallidipes* in neighbouring Mozambique (TTCB, 1992). Much of the area was heavily settled although the distribution of settlement was patchy. The remaining land consisted of a mosaic of alluvial woodland and dry forest, with patches of thicket adjacent to the Ruenya, Nyamusandzara and Mudzi Rivers, which feed in a northeasterly direction through the trial area towards the Zambezi River. A cattle census revealed a population of between eight and twelve cattle per km^2 in the 428 km^2 of the trial area, which should be sufficient for an effective control of tsetse fly by insecticide treatment (Bauer *et al.*, 1992b). However, the cattle were not evenly distributed, reflecting the patchiness of the settlements, and the grazing areas could not be controlled.

The target barrier consisted of blue/black/blue 'S-type' targets (Vale *et al.*, 1988a) with the central black portion of the target treated with deltamethrin 0.54% (Glossinex®, Coopers) and baited with butanone and a mixture of 4-methyl phenol, 1-octen-3-ol and 3-*n*-propyl (Torr *et al.*, 1997). These were arranged in transects 0.5 km apart running in an east-west direction, with targets placed at 0.5 km intervals. The layout was strengthened by additional target lines along the rivers and roads to give an operational density of 5.4 targets per km^2.

The target barrier was supported by the insecticide treatment of cattle in, and adjacent to, the barrier in an area some 20 km wide, west of the tsetse re-invasion front. Some 5 400 head of cattle at three inspection sites in the area (Zano, Kapotesa and Nyamvu, Fig. 5.6.1) were dipped in 0.00375% deltamethrin (Decatix®, Coopers) at two-weekly intervals. After each dipping, the deltamethrin concentration in the dips was checked and, if necessary, adjusted. Whenever dipping could not be conducted (due to water

Figure 5.6.1: Trial area in northeastern Zimbabwe along the border with Mozambique. Targets were placed in transects from left to right every 0.5 km. Additional targets were placed in transects along all the rivers and roads shown on the map, giving a density of 5.4 targets per km^2.



shortage), the cattle were treated with pour-on 1% deltamethrin (Spoton®, Coopers) at monthly intervals. The pour-on was applied in a line along each side of the animal, close to the dorsal mid-line, at a dose of 10ml/100kg body weight. Records were kept of the number of animals treated every month.

5.6.2.2 Tsetse monitoring

Tsetse population monitoring began in January1996 using 54 permanent Epsilon traps (Hargrove and Langley, 1990), baited with mixture of butanone, 4-methyl phenol, 1-octen-3-ol and 3-*n*-propyl phenol (Torr *et al.*, 1997). The traps were spaced at 4 km intervals along the border road, and ≈1 km apart through the trial area, along rivers and roads (Fig. 5.6.1). In addition, from March 1996, five ox-fly-round teams operated between 450 and 500 km of fly-round transect, either each month or every other month. These followed the same defined paths and covered the whole trial area each month. Tsetse catch sites were plotted by geographical co-ordinates, and the distance of each catch from the re-invasion front (easterly side of Fig. 5.6.1) was calculated to facilitate a clear visual presentation of the results. The fly-round teams and the traps were operated until the end of the trial in August 1997.

5.6.2.3 Trypanosomosis monitoring

Monthly trypanosomosis incidence was monitored using nine sentinel herds, each consisting of nine or ten adult cattle (Mashona breed), located at various distances from the tsetse re-invasion front. Three herds grazed along the tsetse invasion front (1, 4 and 7, Fig. 5.6.1), three herds ≈5km into the trial area (2, 5 and 8, Fig. 5.6.1), and three herds ≈10 km into the trial area (3, 6 and 9, Fig. 5.6.1). The sentinel herds followed a strict grazing rota within their allotted grazing areas. Sentinel cattle were not treated with insecticide.

At the start of the trial, all the sentinel animals were ear-tagged and received a curative treatment of diminazene aceturate (Berenil®, Hoechst) by intramuscular injection at a dose of 7.0 mg/kg. Each month, blood taken from the jugular vein of each sentinel animal was examined for trypanosomes (Section 3.3.2.2). Infected animals were cured by intramuscular injection of diminazene aceturate at a dose of 7mg/kg body weight for *T. brucei* or 3.5 mg/kg body weight for *T. congolense* or *T. vivax* infections. The incidence of trypanosomosis was calculated and presented as average incidence at the various distances (0, 5 and 10 km) from the tsetse re-invasion front.

Grazing areas for the local cattle attending the three inspection sites were *ca.* 0-15, 10-18 km and 20-25 km west of the tsetse re-invasion front for Zano, Kapotesa and Nyamvu, respectively. The prevalence of trypanosomosis in these cattle was determined at regular intervals by taking cross-sectional samples of the adult cattle population at each inspection site (Section 3.4.2.1).

5.6.2.4 Experimental design

The target barrier was maintained for eight months until September 1996 when the targets were removed, leaving only the insecticide treatment of the local cattle to stem the tsetse re-invasion. It was planned to have no targets deployed for 12 months, in order to allow for any seasonal changes in tsetse numbers, but, in March 1997 the prevalence of trypanosomal infections in local cattle became unacceptably high and the target barrier was re-deployed in the following month. The tsetse population and trypanosomosis in the sentinel herds continued to be monitored for a further five months.

5.6.3 Results

5.6.3.1 The abundance of tsetse

Glossina pallidipes accounted for 73% of the catch at the Epsilon traps, but only 3.5% of the catch on ox-fly-rounds throughout the trial period. For the analysis, the results from both species were grouped, but the Epsilon trap catches (Table 5.6.1) were predominately *G. pallidipes* whereas the ox-fly-round catches (Table 5.6.2) were predominantly *G. m. morsitans*, reflecting the known sampling biases of these two sampling systems (Hargrove, 1980a).

Table 5.6.1: Catch per trap per day in the trial area, with distance from the re-invasion front. The number of trap days was variable due to trap theft, vandalism, or weather damage.

Distance from re-invasion front:	0-1km	1-2km	2-3km	3-4km	4-5km	5-6km	6-7km
No.traps	19	6	3	7	3	3	13
Traps days (range)	773-380	201-89	116-51	222-124	111-57	112-54	572-287
Target barrier plus cattle treatments							
Jan. 96	0.0194	0.01					
Feb. 96	0.0162	0.012					
Mar. 96	0.0552	0.0152	0.0132	0.0127			
Apr. 96	0.0225	0.0121					
May. 96	0.031	0.0058		0.0126			
Jun. 96	0.0446	0.0051					
Jul. 96	0.013						
Aug. 96	0.0304	0.0076		0.0161			
Cattle treatments only							
Sep. 96	0.0211	0.0047					
Oct. 96	0.0466	0.0075		0.0128			
Nov. 96	0.0579	0.0674			0.0108		
Dec. 96	0.0881	0.0326	0.0196				
Jan. 97	0.0305	0.0052		0.0056	0.0109		
Feb. 97	0.0104	0.0094		0.0106		0.0127	
Mar. 97	0.0064	0.0345		0.0057			
Target barrier plus cattle treatments							
Apr. 97	0.0085	0.0057	0.012				
May. 97	0.0021						
Jun. 97							
Jul. 97							
Aug. 97	0.0056						

Table 5.6.2: Total catch of tsetse from 450 to 500km of ox-fly round covering the trial areas each month, with distance from the re-invasion front.

Distance from re-invasion front:	0-1km	1-2km	2-3km	3-4km	4-5km	5-6km	6-7km	7-8km	8+	Total catch
Target barrier plus cattle treatments										
Mar. 96										0
May 96	1	1	1							3
Jul. 96	7	1								8
Cattle treatments only										
Sep. 96	0	2	11	10	2					25
Oct. 96	12	5	3	9			2		1	32
Nov. 96	5	13	11	6	1	1			1	38
Dec. 96	7	5	5	2	1	3	1			24
Jan. 97	11	5	4	1	3			1	2	27
Feb. 97	6		2	3	2					13
Mar. 97	11	4	3	2					2	22
Target barrier plus cattle treatments										
Apr. 97	7		1							8
May 97										0
Jun. 97		1								1
Jul. 97										0
Aug. 97										0

In both cases the removal of the target barrier in September 1996 caused an increase in the catch along the re-invasion front, and a change in the distribution of the catch as the flies moved into the trial area. The positions of all ox-fly-round catches throughout the experiment are plotted in Figure 5.6.2. Prior to the removal of the target barrier, catches were confined to an area 10-15 km long and stretching 2-3 km into the target barrier (Fig. 5.6.2a). Once the target barrier was removed, the flies quickly moved into the trial block (Fig 5.6.2b, Tables 5.6.1 and 5.6.2) and the fly front, or the area where re-invasion occurred, expanded. When the targets were re-deployed in April 1997, the catch dropped and the position of capture rapidly reverted to the distribution that was seen before the removal of the targets (Fig.5.6.2c). It was not possible to control for seasonal changes in tsetse numbers and their availability at capturing devices, due to the high prevalence of trypanosomosis in the local stock in March 1997 (Table 5.6.3) which caused an early termination of the trial.

Figure 5.6.2: Position of ox-fly-round catches in the trial area; (a) before removal of the targets (total distance covered 1335 km); (b) after removal of the targets (total distance covered 3584 km); and (c) after the targets have been re-deployed (total distance covered 2296 km)

Table 5.6.3: Monthly prevalence of trypanosomosis (%) and average PCV (%) in local stock.

		Sampling site		
Month		Zano	Kapotesa	Nyamvu
Apr. 96	Prevalence	3.3	0	0
	PCV	29.7	32.3	30.5
Jun. 96	Prevalence	0	0	0
	PCV	29.5	30.6	30.3
Oct. 96	Prevalence	0	0	0
	PCV	30.6	32.8	29.9
Dec. 96	Prevalence	0	0	0
	PCV	29.9	31.6	28.9
Mar. 97	Prevalence	19.6	3.3	3.3
	PCV	23.9	32.4	30.4
Apr. 97	Prevalence	3.3	0	0
	PCV	26.3	32.4	31.7
Jun. 97	Prevalence	3.3	0	0
	PCV	28.7	30.3	30.1

However, the pattern of tsetse capture did not follow that which is usually observed due to seasonal changes in Zimbabwe (Phelps and Vale, 1978), suggesting that the expanding population from September through to March was a direct result of the removal of the target barrier. By implication also, the crash in tsetse catch and the immediate restriction in tsetse distribution after the targets were replaced in April 1997, suggest that this was a direct result of the increased mortality imposed on tsetse populations by the targets.

5.6.3.2 Incidence and prevalence of bovine trypanosomosis

Prior to the removal of the target barrier, trypanosomal infections were only diagnosed in sentinel cattle grazing along the tsetse re-invasion front (Fig.5.6.3a). During this period (February 1996-August 1996) the monthly average incidence for

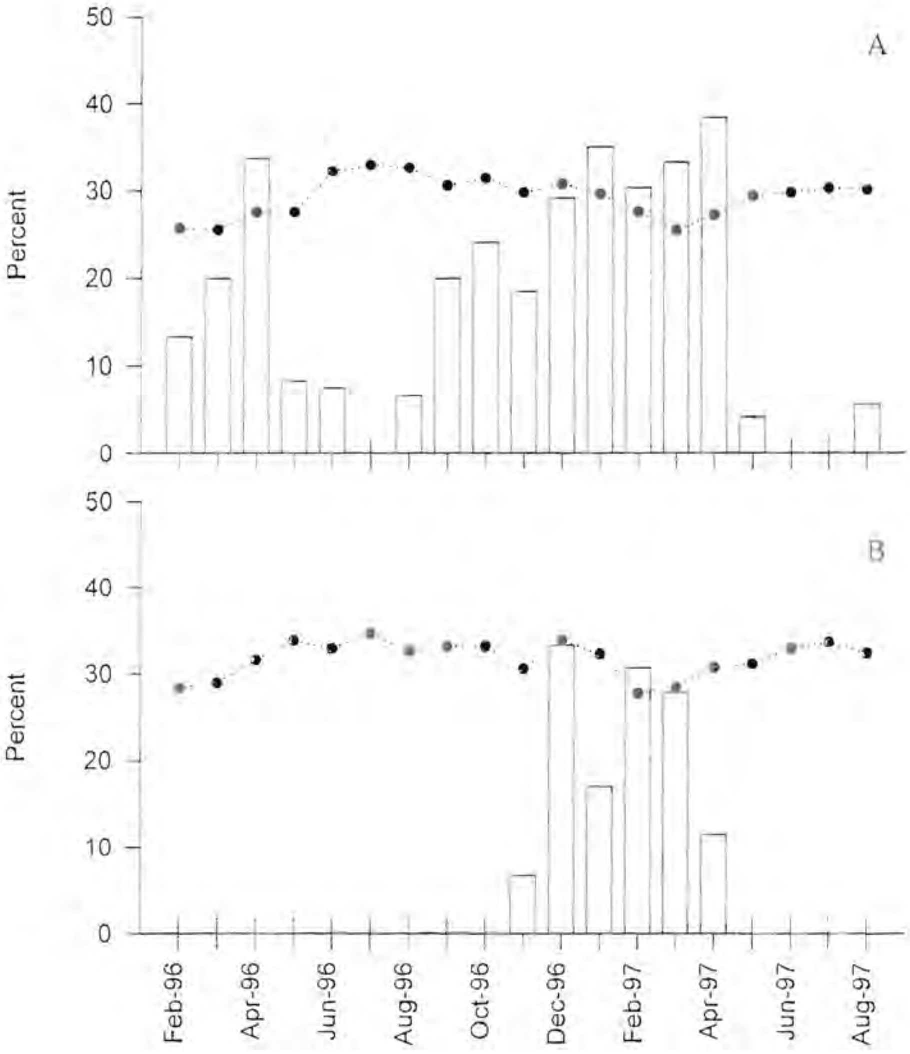


Figure 5.6.3: Incidence of trypanosomosis in sentinel cattle grazed (A) on or very close to the tsetse re-invasion front (herds 1, 4 and 7 of Fig. 5.6.1) and (B) 5 km west of the tsetse re-invasion front (herds 2, 5 and 8 of Fig. 5.6.1). Bars show monthly incidence and dots show average monthly PCV.

the three sentinel herds (1, 4 and 7; Fig 5.6.1) varied from 33.7% in April 1996 to 0% in July 1996 (Fig 5.6.3a). After the removal of the target barrier, the monthly average incidence rose steadily in these herds, reaching a peak of 38.4% the following April. The herds grazing ≈5km from the re-invasion front (2, 5 and 8; Fig 5.6.1), first showed positive to a trypanosomal infection in November 1996, two months after the removal of the target barrier. The trypanosomosis incidence reached 33% in December 1996, and remained high until after the targets were replaced the following April (Fig.5.6.3b).

After re-deploying the target barrier (April 1997), the incidence of trypanosomal infections in all the sentinel cattle returned to a level that was similar to that before the removal of the target barrier.

For seven of the 10 months of the trial period during which targets were present, the monthly average PCVs of sentinel herds grazing along the tsetse re-invasion front were significantly lower ($P<0.05$) than the monthly average PCVs of sentinel cattle grazing either 5 or 10 km from the re-invasion front. The monthly average PCVs of sentinel herds at the tsetse invasion front were highly correlated ($r = -0.90$, $P<0.01$) with the monthly incidence of trypanosomal infections in those animals and reflect the challenge that animals undergo even in the presence of an odour-baited target barrier.

Removal of the target barrier resulted in a decline in the average PCV of herds grazing 5 km from the tsetse re-invasion front (Fig. 5.6.3b) but it did not affect the PCVs of cattle grazing 10 km away. Between January 1997 and April 1997, the average PCVs of sentinel herds grazing 5 km west of the invasion front were not significantly different from those of sentinel herds at the re-invasion front. The re-deployment of targets resulted in a rapid increase in the average PCVs of sentinel herds 5 km west of the invasion front (Fig. 5.6.3b) The prevalence of trypanosomal infections in the local cattle population at each of the three inspection sites was greatly increased by removal of the target barrier (Table 5.6.3).

cases the effect of treatment of cattle on tsetse populations and trypanosomosis *control* was investigated. This is different from our investigation, which was designed to see if treated cattle can prevent tsetse *invasion*. Clearly the answer to this last question, under the circumstances that prevailed, is "no".

Even if tsetse have a high feeding preference for the insecticide-treated animals and a high proportion of the cattle are treated, re-invasion will only be prevented if the treated cattle are evenly distributed over the whole area and if the probability of tsetse contacting treated animals is high. In this trial we had no control over where the cattle grazed at any particular time, and it is probable that for large portions of the trial there were very few cattle, treated or untreated, close to the re-invasion front. Studies in Zimbabwe (Scoones, 1995) have shown that communal cattle grazing patterns can be split according to season. In the cropping season (November-March) cattle are kraaled and herded away from cropped areas, usually under supervision, to protect the crops. In the early dry season (April-July), after the crops have been gathered, the cattle are allowed to roam free and feed unsupervised, mainly on crop residues. As the dry season progresses - late dry season (August - October) - the cattle are forced to move further afield and to graze or browse on diverse food sources. Therefore, one would expect, and observations confirm, a more even distribution of cattle in our trial area during the late dry season and a more patchy distribution at other times of year. This seasonality in the grazing pattern of cattle is common in most communal areas in southern Africa. Consequently, it is almost impossible to assure an even distribution of insecticide-treated cattle throughout the year. This implies that, if insecticide-treated cattle are used to prevent re-invasion of tsetse, the probability of tsetse encountering a treated host will vary according to the season and therefore efficacy of the insecticide-treated cattle barrier will vary accordingly.

It was not possible to test the efficacy of the target barrier in the absence of insecticide-treated cattle. However, the level of management of the target barrier was high and resources were not a limiting factor. Due to the logistical difficulties involved in maintaining a target barrier, and variable resource inputs, it is probably wise to continue insecticidal dipping of cattle in the barrier, to cover for possible breakdowns in barrier efficacy. The additional cost of using a deltamethrin-based dip rather than

5.6.4 Discussion

Under the conditions of this trial, the regular insecticide treatment of cattle did not prevent the tsetse from re-invading the trial area. After the second month without the target barrier in place, tsetse were caught up to 8 km west of the re-invasion front. At the same time, the trypanosomosis incidence in sentinel cattle increased, with a concomitant decrease in the PCV. Furthermore, the high prevalence of trypanosomosis in the local cattle suggested that the insecticide treatments afforded little protection from tsetse challenge and subsequent trypanosomal infection. This is in agreement with the results of Baylis *et al.* (1994) and the results presented in Section 5.4.3. After 7 months, the prevalence of bovine trypanosomosis in the local cattle was unacceptably high in the trial area and the trial was stopped prematurely.

Although it was not possible to investigate the effect of the target barrier in the absence of cattle treatments, it appears that the target barrier performed roughly as has been predicted by a mathematical analysis of tsetse movement (Hargrove, 1993) and earlier experimental investigations (Muzari & Hargrove, 1996). As expected, the targets did not afford complete protection for the cattle herded at the edge of the tsetse re-invasion front, but they gave almost full protection to cattle herded ≈5 km inside the barrier, and complete protection to cattle herded more than 5 km into the area. When the targets were removed, the trypanosomosis incidence in cattle on the re-invasion front and the tsetse catch there increased, indicating that the target barrier was having an effect on the adjacent tsetse populations, as was suggested by Vale *et al.* (1988a).

Previous studies on the effects of insecticide-treated cattle for tsetse control have given mixed but promising results. Bauer *et al.* (1995), working in Burkina Faso, reported good control of tsetse and trypanosomosis in stock using deltamethrin pour-on, and Fox *et al.* (1993) in Tanzania reported reduced tsetse population and increased herd health after the deltamethrin treatment of cattle on a large commercial ranch. Baylis & Stevenson (1998), reporting on a trial on the Galana Ranch in south-east Kenya, concluded that the effect on herd health was greater than could be expected from the minimal effects on tsetse density caused by cattle treatments. In all of these the routinely used acaricide is low compared to the cost of mopping up tsetse populations that become established after penetrating a poorly maintained target barrier.

- Monthly deltamethrin treatment coverage of adult cattle in the trial area varied between 76 and 87% of the total cattle population. This variability is explained by the poor turn-out at dips on wet days, a failure of stock owners in outlying homesteads to trek to the inspection sites every time, and the free roaming of cattle during the dry season.

5.7 The large-scale use of a 1% cyfluthrin pour-on (Cylence®, Bayer) to control bovine trypanosomosis in eastern Zambia

5.7.1 Introduction

In the mid-1900s, the attractiveness of hosts to tsetse was first exploited as a tsetse control method (Whiteside, 1949; Vanderplank, 1947; Du Toit, 1954). Despite initial successes, this promising tsetse control method was abandoned because of the low persistence of the insecticides used.

It took almost 40 years before the method was taken up again. This was a result of the discovery of the persistent and less toxic synthetic pyrethroid, deltamethrin. The first controlled study on the persistence of the toxic effect to tsetse of deltamethrin spray, applied to cattle, was conducted in Zimbabwe (Thomson, 1987). Results of the trials indicated a high mortality in *G. pallidipes* and *G. m. morsitans* within the first two weeks of deltamethrin treatment followed by a period characterised by a long-lasting knock-down effect.

The promising results of the initial controlled trials were followed by several field trials in the southern African Region. A small-scale trial, conducted in the Eastern Province of Zambia, involving the weekly dipping in deltamethrin of 400 head of cattle, resulted in a reduction of the trypanosomosis incidence from 40% at the beginning of the trial to 5% eight months later (Chizyuka and Luguru, 1986). Similar effects were observed in other parts of Zambia (Wiersma and Schoonman. 1992) and in Zimbabwe (Thompson *et al.*. 1991). Despite the successful application of this method in other parts of Africa (Bauer *et al.*, 1988; Bauer *et al.*, 1992b; Fox *et al.*, 1993; Leak *et al.*, 1995; Bauer *et al.*, 1995), it has not been used widely in southern Africa. This is largely a result of the strategy of tsetse eradication from large areas where cattle are absent. However, the shift from a strategy of tsetse eradication to localised trypanosomosis control makes the insecticide treatment of cattle an attractive method of control. To evaluate the effectiveness of the method in an intensively cultivated area of southern Africa where bovine trypanosomosis was endemic, a trial was initiated in eastern Zambia. Use was made of a 1% cyfluthrin pour-on (Cylence®, Bayer) formulation.

5.7.2 Materials and methods

5.7.2.1 Trial area

The trial was carried out in an area of about 2 000 km^2 situated between 30°44'and 31°08' E and between 14°07' and 14°42' S in Petauke and Nyimba Districts of the Eastern Province of Zambia (Fig. 5.7.1). The area is intensively cultivated and carries a cattle population (Angoni breed) of *ca.* 11 animals/km^2 (based on an aerial survey conducted in August 1997). The total number of adult cattle in the area was 20 130 (based on census figures of the Department of Veterinary Services). Vegetation and climate are described in Section 2.2.2.1. *Glossina m. morsitans*, the only tsetse species present, takes most of its blood meals from cattle (Section 2.3.3). Tsetse-transmitted bovine trypanosomosis was endemic (Fig. 5.7.1) with a monthly average incidence of 9.7% (Section 2.5.3.4). The index of abundance of tsetse explains 74% of the variance in the incidence (log transformed) of nagana (Section 2.5.3.4).

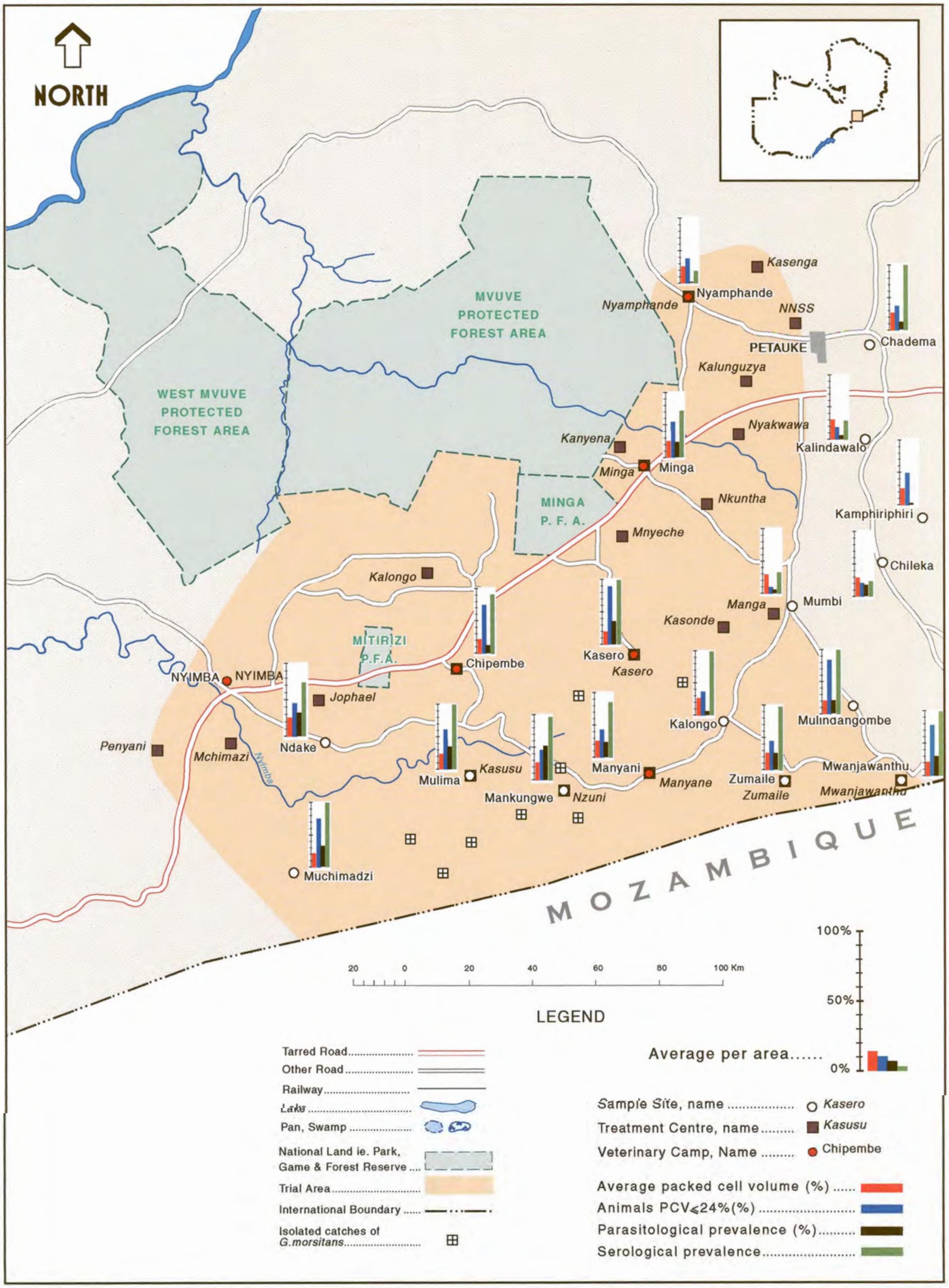
5.7.2.2 Insecticide treatments

A 1% cyfluthrin pour-on (Cylence®, Bayer) was applied in one line along the spine of the animal, from shoulder to tail base, at a dose of 15 ml/100 kg body weight using an automatic pour-on applicator. Treatments started in November 1998 and were repeated at *ca.* 7-week intervals. They were applied free of charge. To facilitate the treatment of all adult cattle in the trial area, 22 treatment centres were established. They were supervised by 7 veterinary camps (Fig. 5.7.1). Records were kept of the number of animals treated at each centre during each treatment. The total number of animals treated was expressed as a proportion of the total number of animals in the trial area.

5.7.2.3 Trypanosomosis monitoring

The effect of the application of the pour-on on the tsetse population was monitored indirectly by determining the incidence of trypanosomosis in eight sentinel

Figure 5.7.1: Map of the trial area indi centres, location of sentinel herds, bovine trypanosomosis and tsetse survey results.



herds situated throughout the trial area (Fig. 5.7.1). Each herd consisted of 20, eartagged, adult Angoni cattle. They were kept under traditional village management but not treated with cyfluthrin pour-on. Each month blood collected from each sentinel animal was examined using parasitological diagnostic methods (Section 3.3.2.2). Animals infected with trypanosomes received a curative treatment of diminazene aceturate (Berenil®, Hoechst) by intramuscular injection, at a dose of 7mg/kg body weight for *T. brucei* or 3.5 mg/kg body weight for *T. congolense* or *T. vivax*,.

To evaluate objectively the cattle owner's perception of the effect of the pour-on on animal condition, records were obtained from the Veterinary Offices of the Districts on the sales of diminazene aceturate (Berenil®, Hoechst). Diminazene aceturate sales to cattle owners between January 1999 and June 1999 were compared with the sales during the same period in 1998.

5.7.3 Results

5.7.3.1 Proportion of animals treated

The number of animals treated with the cyfluthrin pour-on, expressed as a proportion of the total number of animals in the trial area, increased throughout the trial. It was low (47%) during the first treatment but increased gradually (Fig. 5.7.2). It was again low (about 30%) during the last two treatments (Fig. 5.7.2).

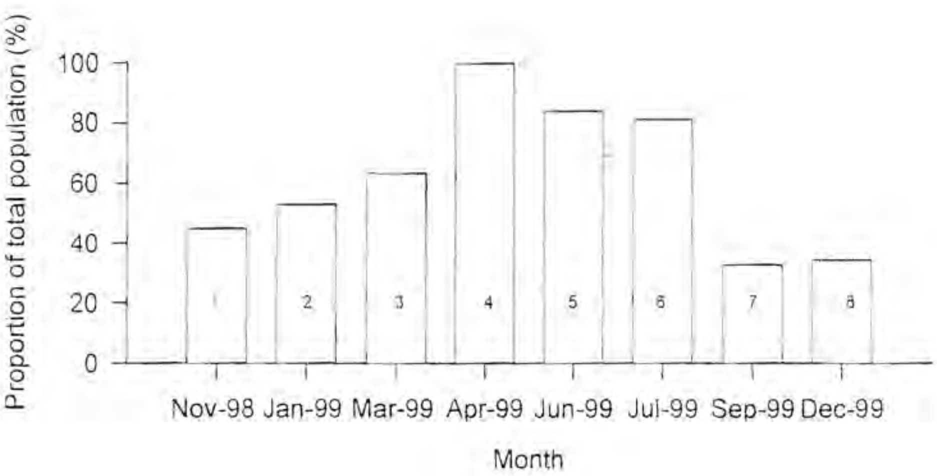


Figure 5.7.2: Proportion of the total cattle population treated with cyfluthrin pour-on during consecutive treatments.

5.7.3.2 Incidence of bovine trypanosomosis

During the first eight months of the trial (November - June), the monthly mean incidence of trypanosomosis in the sentinel herds differed little from the the monthly mean incidence before treatment was initiated (Fig. 5.7.3).

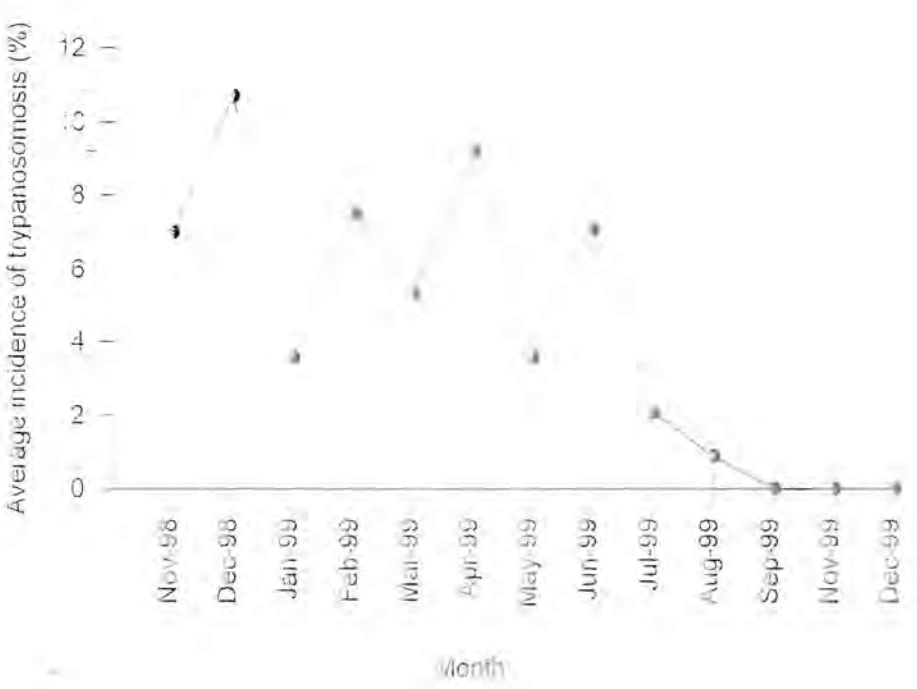


Figure 5.7.3: Monthly average incidence of trypanosomal infections in sentinel herds.

From July onwards, however, the monthly mean incidence started to decline steeply. It reached 0.8% in August. From September onwards no trypanosomal infections were detected.

Between January 1999 and June 1999 a total of 3 738 doses of diminazene aceturate were sold compared to 13 134 doses during the same period in 1998.

5.7.3.3 Packed cell volume

The application of the pour-on resulted in an immediate increase in the average PCV of the sentinel cattle. The average PCV remained relatively high (compared to the PCV values during the months preceding the start of the pour-on application) during treatment period (Fig. 5.7.4). It reached peak values of on average 32.4% between September and December 1999.

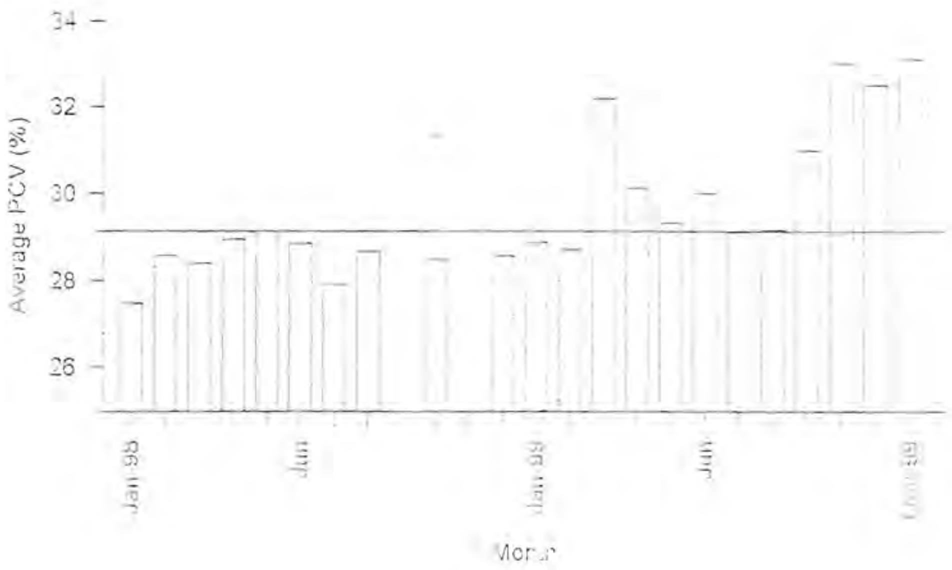


Figure 5.7.4: Monthly average PCV of sentinel cattle before and after the start of the pour-on application.

5.7.4 Discussion

5.7.4.1 Effect of cyfluthrin pour-on on the incidence of nagana

Several studies have shown that regular treatment of cattle with pyrethroid insecticides such as deltamethrin, flumethrin or cypermethrin can significantly reduce the incidence of nagana (e.g. Chizyuka and Luguru, 1986; Bauer *et al.*, 1992; Leak *et al.*, 1995). Results from this trial show that a 1% cyfluthrin pour-on (Cylence®, Bayer) applied at 15 ml/100 kg body weight at 7-week intervals also results in a significant reduction in the incidence of bovine trypanosomosis. However, a significant effect on the incidence of bovine trypanosomosis was only observed eight months after the application started (July 1999). Several reasons explain this delayed effect. First, the proportion of animals treated between November 1998 and March 1999 was substantially lower than the total coverage between March 1999 and July 1999. Despite an intensive extension exercise, the low turn-up is explained by the presence of crops in the fields during the rainy season. This made it difficult for a large proportion of the cattle owners to reach the nearest treatment centre. Second, mud on the skin of treated animals and heavy rain showers may have reduced the availability of the insecticide to tsetse during the rainy season. A second possible reason for the sudden increase in the effectiveness of the pour-on in July is the ecology of tsetse in the trial area. Throughout the trial area, tsetse are highly dependent on cattle as their source of food (Section 2.3.3). Because of this dependence, seasonal changes in the grazing patterns of cattle affect the distribution and abundance of tsetse (Sections 2.2.3 and 2.4.3). Such a sudden change in the grazing pattern of cattle occurs in June/July, when cattle are allowed to roam freely (Section 2.2.4). The abrupt reduction in host availability together with the high proportion of cattle treated with cyfluthrin in June probably contributed significantly to the reduction in the density of the tsetse population and concomitant reduction in the incidence of bovine trypanosomosis.

The high proportion of animals treated during this period seems to have had a severe impact on the tsetse population density. Indeed, despite the low treatment frequency from September onwards no trypanosomal infections were detected in the sentinel cattle.

5.7.4.2 Effect of cyfluthrin pour-on on packed cell volume

Whereas the effect of the application of the pour-on on the incidence of nagana was only seen clearly eight months after the start of the application, the effect on the herd average PCV was observed from four months (March 1999) onwards. Between March 1999 and December 1999, the monthly herd average PCV was either equal to or higher than the maximum monthly average PCV recorded during the period preceding the pour-on treatments. Since the first months of treatment had little effect on the incidence of nagana, the increase in average PCV may be attributed to the effect of the cyfluthrin treatment on ticks and, hence, tick-borne disease challenge.

Babesiosis and anaplasmosis occur in the trial area. Both tick-borne diseases cause anaemia and significantly reduce the PCV (Section 3.3.3, Table 3.3.1). Cyfluthrin applied at the dose rate and treatment interval used in this trial is an effective acaricide. It is, therefore, not surprising that the average PCV of the sentinel cattle increased substantially even during periods of highest tick challenge. This effective control of ticks (including *Rhipicephalus appendiculatus*) contained an East Coast Fever (*Theileria parva parva*) outbreak that occurred during the trial period in Petauke (Lubinga, pers. comm.).

The increase in the herd average PCV is probably the best reflection of the improved condition of cattle in the trial area after cyfluthrin treatments were initiated. An indirect reflection of this improved herd health is the substantial reduction in the sales of diminazene aceturate (Berenil®, Hoechst). The majority of the cattle owners (85.1%) in the trial area use trypanocides (Section 5.2.3.1, Table 5.2.1). In the absence of microscopic diagnosis, treatment was usually given to clinically sick animals or animals in poor condition (Section 5.2.4.2). An improvement in animal condition resulting from a reduction in tsetse and, especially during the first months of the trial, tick challenge may be the most likely explanation for the reduction in diminazene aceturate sales. Similar indirect results have been observed elsewhere with other pyrethroid insecticides (Bauer *et al.*, 1992; Baylis and Stevenson, 1998; Bauer *et al.*, 1999).

CHAPTER SIX

CONCLUSIONS

The formulation of a strategy for the sustainable control of tsetse-transmitted bovine trypanosomosis is a dynamic process in which areas suitable for control are identified, ranked and adjusted over time. The control strategy addresses questions such as *where, how, why, when, by whom,* and *for what benefits and costs* nagana should be controlled. To answer these questions accurately, potential control options are screened by carefully considering socio-economic, technical, environmental and institutional criteria.

The work presented in this thesis aimed at contributing to a framework for the formulation of appropriate strategies for the sustainable localised control of tsetse-transmitted bovine trypanosomosis in southern Africa. Some of the questions mentioned above were addressed, after considering carefully the technical and socio-economic criteria.

A prerequisite for the development of a strategy for the sustainable control of tsetse-transmitted bovine trypanosomosis is accurate knowledge of the distribution of the disease. Usually, the distribution of nagana is established by determining the distribution of cattle with trypanosomal infections. The diagnosis of bovine trypanosomosis is, however, fraught with difficulties. Because of the low diagnostic sensitivity of the commonly used parasitological diagnostic tests, areas where bovine trypanosomosis is present at low prevalence or where it occurs seasonally are often missed. Hence, maps of the parasitological distribution of bovine trypanosomosis often provide an inaccurate basis for the formulation of a control strategy. In Malawi and Zimbabwe, for example, large areas where bovine trypanosomosis occurs would not have been identified if reliance had been placed only on parasitological diagnostic methods (Sections 3.4.3 and 3.6.3). This sensitivity problem could be solved largely by using the recently developed PCR method (Section 1.3.2.3). The test is promising but not yet available for use in large-scale surveys. However, by sampling a sufficiently large part of the population, and by combining parasitological diagnostic methods with indirect tests, a more accurate picture of the distribution and the dynamics of the disease can be obtained that could form a sound basis for strategy formulation (Sections 3.4, 3.5 and 3.6). Such indirect tests detect the animal's immune response to trypanosomal infection, and include the anti-trypanosomal antibody-detection ELISA (antibody-ELISA). The high sensitivity and specificity of the antibody-ELISA improves accuracy and also, and of equal importance, this ELISA detects anti-trypanosomal antibodies that persist in cattle long after infections have been cured (Section 3.2.3). As a result, areas of low or irregular tsetse challenge can be identified in the absence of the causal agent.

The value of a diagnostic test such as the antibody-ELISA depends on its characteristics. These characteristics can be defined in terms of repeatability, sensitivity and specificity. The antibody-ELISA used in the work presented in this thesis had high repeatability (Section 3.2.3). Furthermore, the test's sensitivity and specificity for anti-*T. congolense* antibodies was high (Sections 3.3.2 and 3.3.3) and non-specific cross reactions with antibodies against *B. bigemina* and *A. marginale* were not found to occur (Section 3.3.3). The test's sensitivity and specificity for antibodies against pathogenic trypanosome species other than *T. congolense* requires further investigation. However, since use has been made of antigens derived from whole trypanosomes the test was probably not species-specific (Section 3.5.3.3). The standardization of technical parameters and continuous quality control are essential steps towards the sustained use of the antibody-ELISA. Standardization could be improved by introducing defined recombinant antigens. The use of representative reference standards as routine quality controls would ensure accurate test results. Failure to standardise and validate the antibody-ELISA may produce incorrect results that will constitute a false basis for the formulation of a strategy for the control of bovine trypanosomosis.

A variety of methods are available to control nagana (Section 1.5). Most of them have been developed with large-scale vector control in mind (Section 1.5.2). On a smaller scale, the suitability of a control method or combination of methods is likely to depend on the local circumstances. In southern Africa, bovine trypanosomosis occurs in areas where cattle are kept inside or adjacent to a tsetse-infested area (Chapter 3). The areas where cattle are kept inside a tsetse-infested zone are generally well-known. The eastern plateau of Zambia is such an example (Chapter 2). Usually, however, tsetse and cattle do not occur in the same area and the distribution of bovine trypanosomosis is restricted to the zone where the tsetse-belt and the cattle grazing areas overlap (the "cattle/tsetse interface"). In such areas, nagana is an "ecotonal or edge" problem. Three types of cattle/tsetse interface have been identified in southern Africa, *i.e.* (i) areas where cattle are kept immediately adjacent to a tsetse-infested zone, (ii) areas where bovine trypanosomosis is prevalent because of the occasional or seasonal invasion by tsetse into the tsetse-free area, and (iii) areas where bovine trypanosomosis is present because of small, often unidentified, tsetse pockets (Chapter 3).

(i) *Areas where cattle are kept immediately adjacent to a tsetse-infested zone*

This type of cattle/tsetse interface is common in Malawi where the distribution of tsetse is restricted to national parks, game reserves and forest reserves. Bovine trypanosomosis is prevalent in the adjacent, tsetse-free, areas (Section 3.4.3.4). A similar cattle/tsetse interface occurs in areas where the movement of tsetse is restricted because of natural or artificial barriers. In the Eastern Caprivi, for example, the Zambezi River restricts the spread of tsetse from the Sesheke area of Zambia into the Katima Mulilo area. Nevertheless, cattle are still challenged when moving into or close to tsetse-infested areas in Zambia (Section 3.5.3). A similar situation occurs along Zimbabwe's eastern/ northeastern border where an artificial barrier (odour-baited, insecticide-treated, targets) separates the tsetse-belt in Mozambique from the tsetse-cleared areas in Zimbabwe (Section 3.6.2.2).

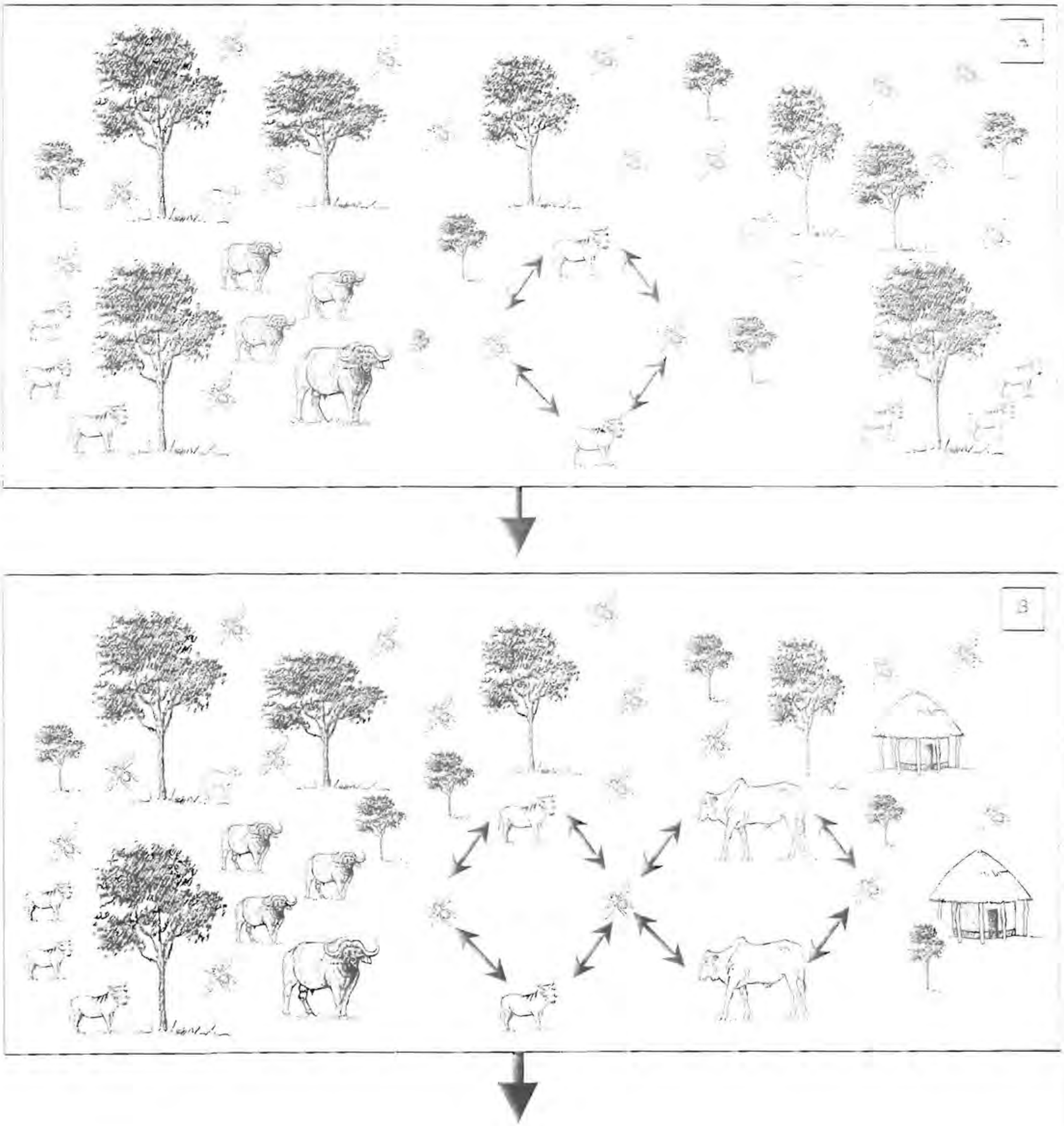
(ii) Areas where bovine trypanosomosis occurs because of occasional or seasonal invasion by tsetse.

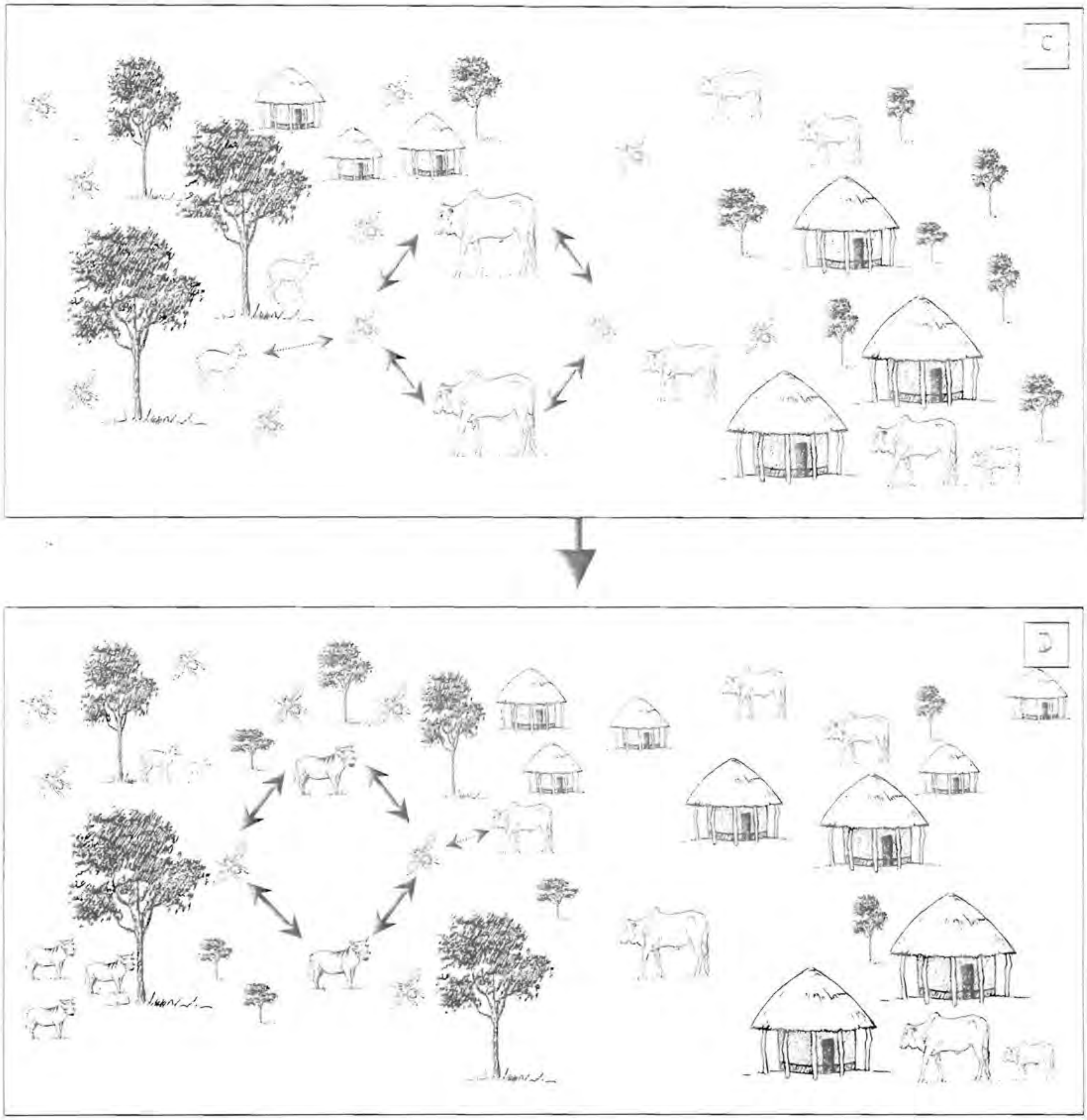
This type of interface is again common in Malawi where bovine trypanosomosis occurs far outside know tsetse foci (Section 3.4.3.4). It is attributed mainly to the seasonal movement of tsetse along rivers such as the South Rukuru River in the Northern Region of the country (Section 3.4.4.2).

(iii) Areas where bovine trypanosomosis is present because of small, often unidentified, tsetse pockets.

This type of cattle/tsetse interface occurs in Malawi where *G. brevipalpis* is present in several small unidentified foci and in western Zimbabwe where small foci of tsetse (probably *G. pallidipes*) have gone undetected for the past 20 years (Sections 3.4.3 and 3.6.3).

Figure 6.1: The consequences of gradual encroachment of people and cattle into a tsetse-infested area on the epidemiology of bovine trypanosomosis.

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Cattle kept in a tsetse-infested area

A usual consequence of the introduction of people and cattle into tsetse-infested areas is a reduction of the habitat suitable for tsetse because of the clearing of vegetation for cultivation and a reduction in the density of game animals (Figs. 6.1a-c). Tsetse adapt rapidly to the reduced availability of wild hosts by increasing the proportion of feeds that they take from cattle. Ultimately, the flies become highly dependent on cattle for their survival. In some areas of eastern Zambia, for example, tsetse take 75% of their blood meals from cattle (Section 2.3.3). The high dependence of tsetse on cattle as source of food and the gradual reduction in suitable tsetse habitat have important repercussions (Sections 2.2 and 2.4), which should be taken into consideration when a strategy for the localised control of bovine trypanosomosis is formulated.

Because of the close relationship between cattle and tsetse, bovine trypanosomosis has an endemic character. Its incidence is correlated with the density of the tsetse population (Section 2.5.3.4), which in turn, can be exploited in the timing of prophylactic trypanocidal drug campaigns. Increasing the mortality rate in the tsetse population has two effects on the transmission of nagana. First, increased tsetse mortality will have an immediate and significant effect on the incidence of bovine trypanosomosis (Sections 5.3.3 and 5.7.3). Second, because of the age-dependent prevalence of trypanosomal infections in tsetse, it will reduce the infection rate in the fly population (Section 2.5.3.3).

Probably the most appropriate method of controlling a tsetse population that is highly dependent on cattle as its food source is the treatment of cattle with insecticides. This method was highly effective in eastern Zambia but only after a high proportion of the cattle population was treated, over a large area for 6 consecutive months (Sections 5.4 and 5.7). Stationary baits also were highly effective in controlling tsetse in cultivated areas and seasonal variations in the distribution of cattle and tsetse have been exploited successfully by deploying stationary baits in selected habitats (Section 5.3). Furthermore, the effectiveness of a control operation can be increased if it starts just before the time that the tsetse population is subject to additional mortality, caused, for example, by the sudden changes in the grazing pattern of cattle.

Cattle kept at the cattle/tsetse interface

In areas where cattle are kept at the edge of tsetse-infested areas (usually game reserves) (Chapter 3) or where cattle are subject to seasonal challenge by tsetse, the importance of cattle as hosts is likely to be minimal. Consequently, cattle are challenged at irregular intervals and the level of challenge is not necessary correlated with the density of the tsetse population. Bovine trypanosomosis, therefore, has an epidemic character at the cattle/tsetse interface. Such nagana epidemics occurred along the Kasungu National Park in Malawi in the mid-1980s, and along Umfolozi Game Reserve in Zululand (South Africa) in 1990. In such situations, control methods should aim at either controlling the tsetse population in the tsetse-infested area or reducing the interaction between tsetse and cattle along the interface. Odour-baited, insecticide-treated targets are effective in controlling tsetse in game areas but are also very effective in reducing the contact between tsetse and cattle at the edge of such tsetse-infested areas. Moreover, they prevent the spread of tsetse from an infested area into a tsetse-free area (Section 3.4.3, 3.5.3 and 3.6.3). The treatment of cattle with insecticides at the edge of a tsetse-infested area is unlikely to have a dramatic effect on the density of tsetse inside the tsetse-infested zone. Furthermore, the insecticide treatments will not protect the animal from tsetse challenge (Section 5.4.3). It is, therefore, an inappropriate method in such situations. The simplest and probably most effective method would be to prevent cattle from grazing in the vicinity of the tsetse-infested area. However, severe pressure for land often makes it impossible to change grazing patterns and to enforce restrictions on livestock movement.

The direct and indirect socio-economic impacts of bovine trypanosomosis on agricultural development are important determinants in the selection of priority areas for the localised control of bovine trypanosomosis. The indirect impacts on agricultural production and farming practices are often difficult to quantify. Furthermore, they vary substantially between areas (Section 4.3.3). The direct impacts, on the other hand, are easier to quantify. In southern Africa, nagana has a direct impact mainly on adult mortality and calving rates (Section 4.3.3). The degree to which both production variables are affected by the disease is, however, determined by factors such as the innate and acquired immunity to the disease (see below) and stress factors (Section 4.2.3). Trypanocidal drug treatments also may significantly affect the direct impact of nagana on especially mortality rates (Section 4.3.3). Consequently, the socio-economic impacts of bovine trypanosomosis on agricultural development are subject to significant temporal and spatial variations. Since the sustainability of a control intervention will depend largely on the benefits accruing from it, decisions to intervene or not should be based on an objective assessment of the local impacts of the disease.

The high dependence of tsetse on cattle as a source of food also has a repercussion on the impact of bovine trypanosomosis. Several field studies in tsetse-infested areas of Africa (Section 1.4.2.2) have demonstrated that susceptible cattle breeds which survive trypanosomosis because of treatment with trypanocides or because of self-cure are subsequently more resistant to rechallenge with the same serodeme(s). Such immunity is likely to develop in areas where trypanocides are used and where a resident tsetse population feeds almost entirely on cattle. This is the case in some parts of eastern Zambia (Sections 2.3.3 and 5.2.3). Furthermore, the close interaction between tsetse and cattle must have played a role in the natural selection of the indigenous cattle population and the gradual disappearance of highly pathogenic trypanosome strains and trypanosome species such as *T. vivax*. It is, therefore, not surprising that results from the socio-economic surveys conducted in the Petauke District of the Eastern Plateau in Zambia suggest some degree of resistance to trypanosomosis in the resident cattle population (Sections 4.2.3 and 4.3.3).

Because of the irregular challenge and the high proportion of new trypanosome strains in tsetse acquired from game animals, protective immunity to trypanosomal infections is unlikely to develop in cattle along the cattle/tsetse interface. Furthermore, no selection has occurred against highly pathogenic trypanosome strains. The impact of bovine trypanosomosis along such interfaces is, therefore, expected to be higher (Chapter 4). In areas where curative trypanocidal drugs are used, this higher impact directly affects reproduction in cattle, hence the lower calving rates in cattle kept along the Vwaza Game Reserve in Malawi but also in the Chipangali area of eastern Zambia where cattle are challenged by tsetse from the Kasungu National Park and Lukusuzi Game Reserve (Section 4.3.3.3). In areas where trypanocides are not routinely used, high mortality rates are expected. Such high mortality rates were observed during the nagana epidemics along the edge of the Kasungu National Park and adjacent to the Umfolozi Game Reserve. The significant effects of trypanosomosis on cattle production and the potential for devastating nagana epidemics along the cattle/tsetse interface should be considered when formulating a strategy for the localised control of bovine trypanosomosis.

The level of resistance to trypanosomosis in cattle is an important determinant in strategy formulation. A useful indicator of resistance to trypanosomosis can be obtained by establishing the relationship between herd average PCV and prevalence of trypanosomal infections in an area (Section 4.3).

In many parts of Africa, trypanocidal drug treatments constitute the principal method of controlling bovine trypanosomosis. Despite the availability of various effective vector control methods it is likely that, in the foreseeable future, chemotherapy and chemoprophylaxis will continue to contribute significantly to the control of the disease. Furthermore, trypanocidal drug treatments play a crucial role in the acquisition of immunity in cattle kept in tsetse-infested areas (Sections 4.2.3 and 4.3.3). In areas where resistance in trypanosomes to trypanocidal drugs is absent or present at low prevalence, the sustainability of a drug-based control strategy will depend on the risk of large-scale resistance development. Surveys to investigate the trypanocidal drug-use practices by cattle owners provide a useful baseline to indicate the likelihood of the development and spread of such resistance (Section 5.2.3) and, therefore, should form part of the control strategy formulation process. Furthermore, the results of drug-use surveys provides a good picture of the farmer's attitudes towards control of cattle diseases and the manner in which they spend money on veterinary medicines. This information is important when determining the appropriateness of a strategy for the control of bovine trypanosomosis, in particular, and animal health in general.

The appropriateness of a tsetse control method will depend on its suitability, transferability and sustainability. The suitability of a control method is a technical question, which involves an assessment of the technical efficiency of a method under a particular situation. The results presented in this thesis indicate that odour-baited targets are suitable in all epidemiological situations. They are effective in clearing tsetse from relatively small areas and are effective barriers against tsetse re-invasion (Sections 5.3.3, 5.6.3, 3.4.3, 3.5.3 and 3.6.3). The use of insecticide-treated cattle, on the other hand, is most effective when it is restricted to areas where the tsetse population is isolated or where reinvasion of flies is low. Furthermore, insecticide treatments of cattle do not provide an effective barrier against the invasion of tsetse in the areas studied here (Section 5.6.3).

The transferability of a tsetse control method is influenced by the willingness and ability of a farmer to adopt a particular technique or combination of techniques. It was beyond the scope of this thesis to study in depth the sociological aspects of trypanosomosis control. However, the results of the drug-use survey clearly showed that cattle owners in southern Africa have a curative approach towards the control of nagana (Section 5.2.4.2). In the absence of widespread trypanocidal drug resistance, transferability of tsetse control methods that are essentially prophylactic measures may be low. The sustainability of a control method involves an assessment of the ability of a farmer or community to sustain the use of a technique or combination of techniques. Of particular importance are the risks associated with unwanted side effects such as the development of resistance in trypanosomes to trypanocidal drugs (Section 5.2.3) or the effect of pour-on treatments on enzootic stability in cattle against some tick-borne diseases (Section 5.5.3). Furthermore, the implementation of tsetse control operations in areas where cattle have developed immunity to the disease is likely to result in the loss of such immunity. Whereas this may not be a problem as long as tsetse control measures are effective, the loss of immunity may have important consequences after the tsetse control operation collapses and a highly susceptible cattle population becomes subject to tsetse challenge.

The formulation of a strategy for the sustainable localised control of bovine trypanosomosis is a dynamic process that has to take into account a wide range of variables that determine the epidemiology of the disease and, hence, its appropriateness in a particular area. Several of the variables have been presented and discussed in this thesis. It is not difficult to imagine that the various epidemiological situations that were identified are part of a logical sequence triggered by a single phenomenon, *i.e.* the encroachment of people and their livestock into tsetse-infested areas. Human encroachment directly affects the population densities of cattle and game animals, the availability of suitable habitat for tsetse. These factors and their consequences for the impact of bovine trypanosomosis determine, to a large extent, the appropriateness of strategies for the sustainable localised control of tsetse-transmitted bovine trypanosomosis in southern Africa (Table 6.1 and Figs. 6.1a-c).

Previously, strategy formulation for *large-scale eradication* of tsetse in southern Africa was dominated by straightforward technical considerations. The most cost effective and technically efficient means of controlling tsetse in an area was emphasised. The success of a control intervention was largely dependent on the availability of manpower, equipment and the organizational capacity of the implementer. Results of this thesis have shown that the planning for the *sustainable localised control* of bovine trypanosomosis is a multidisciplinary exercise that requires a good understanding of the distribution and epidemiology of the disease. This will require the necessary expertise to analyse the local situation and draw conclusions relevant to the formulation of a control strategy. However, it may be facilitated greatly by the use of geographical information systems. The choice of a particular control method will depend largely on the local epidemiological situation. By distinguishing the different epidemiological situations in southern Africa and by analysing their characteristics, appropriate methods to control bovine trypanosomosis have been identified. This thesis has, therefore, contributed to a better understanding of the epidemiology and control of bovine trypanosomosis in southern Africa and made a significant contribution to the development of a framework for the formulation of appropriate strategies for the effective control of tsetse-transmitted bovine trypanosomosis in the southern African region.

Table 6.1: Expected effects of the introduction of cattle and vegetation clearing in a tsetse-infested area on the epidemiology, impact and control of bovine trypanosomosis (- = no impact, + = slight, ++ = intermediate, +++ = great).

Events	Figure	Population density			Host preference		Disease	Suitability of control method[2]		
		Tsetse	Cattle	Game	Game	Cattle	impact	Trypanocides[1]	Targets	Insecticide-treaments
Cattle-free, tsetse-infested area	6.1a	+++	-	+++	+++		-	-	+++	-
Introduction of cattle and people	6.1b	+++	+	++	++	+	+++	++	+++	-
Progressive clearing of vegetation	6.1b	++	++	+	+	++	++	+++	+++	+++
Significant reduction in tsetse habitat	6.1c	+	+++	+	+	+++	++	+++	+++	+++
No habitat left, challenge only at interface	6.1d	+	+++	+	+++	+	+++	+++	+++	-

[1] Trypanocidal drug resistance is not present
[2] Not taking into account transferability and sustainability