THE DEVELOPMENT OF A NEW STRATEGY FOR THE SUSTAINABLE CONTROL OF BOVINE TRYPANOSOMOSIS IN SOUTHERN AFRICA

BY

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A thesis submitted to the University of Pretoria in the Faculty of Veterinary Science in fulfilment of the requirements for the degree

PHILOSOPHIAE DOCTOR

PRETORIA 2000

I declare that the thesis, which I submit hereby for the degree Philosophiae Doctor at the University of Pretoria is my own work and has not been submitted previously for a degree at any other university.

.....

Peter Van den Bossche

16 May 2000

I certify that the deponent acknowledged that he knew and understood the contents of the above declaration, did not have any objection to taking the prescribed oath and considered it to be binding on his conscience. I thereafter administered the oath by causing him to utter the following words: "I swear that the contents of this declaration are true, so help me God" — and thereafter the deponent in my presence signed the declaration at PRETORIA on which date and which place I also signed this certificate:

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SUMMARY

THE DEVELOPMENT OF A NEW STRATEGY FOR THE SUSTAINABLE CONTROL OF BOVINE TRYPANOSOMOSIS IN SOUTHERN AFRICA

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Previously, strategy formulation for large-scale eradication of tsetse in southern Africa was dominated by straightforward technical considerations. The current shift to localised control of tsetse-transmitted bovine trypanosomosis has changed the emphasis from the vector to the disease. Nagana remains the main reason for intervening but control methods will differ according to the local situation and interventions will be restricted to those areas where the disease is present. As a result,

the technical criteria to be considered will differ substantially from those considered in the planning for large-scale eradication. First, a clear picture of the extent and magnitude of the bovine trypanosomosis problem is required. Second, the selection of the most efficient intervention methods will vary according to the local epidemiological situation. Hence, the different epidemiological situations need to be identified and the effectiveness of available control methods needs to be evaluated in each of these situations. Finally, the long-term sustainability of an intervention will depend, to a large extent, upon the socio-economic impact of the disease and perceived benefits accruing from its control.

Tsetse-transmitted bovine trypanosomosis occurs in large areas of Malawi, Zambia, Zimbabwe and Namibia. The epidemiology of the disease differs substantially between areas. On the plateau of eastern Zambia, for example, cattle are kept in a tsetse-infested area. Because of the encroachment of people and cattle into the tsetse-infested area and the concomitant reduction in the number of game animals, tsetse have become highly dependent on cattle as their source of food. As a result, the distribution and density of tsetse is determined largely by the distribution and changes in the distribution or grazing pattern of cattle. *Trypanosoma congolense* is the main trypanosome species in tsetse and cattle. The prevalence of *congolense*-type trypanosomal infections in tsetse undergoes little variations between months and is affected mainly by the average age of the tsetse population. The incidence of bovine trypanosomosis is significantly correlated with the density of the tsetse population.

Bovine trypanosomosis is also prevalent in areas where cattle are kept adjacent to a tsetse-infested zone or where tsetse occasionally invade a tsetse-free area. In Malawi, for example, the main foci of bovine trypanosomosis are located adjacent to tsetse-infested national parks, game reserves or forest reserves. Bovine trypanosomosis also occurs far outside the known tsetse foci because of the seasonal movement of tsetse along rivers or because of, often small, undetected tsetse foci. Such foci have been detected in Malawi and in Zimbabwe. In most of the areas, bovine trypanosomosis is caused by *T. congolense*. However, the prevalence of *T. vivax* infections is high in areas where tsetse take a large proportion of feeds on game animals. This is the case in the Mamili area of the Eastern Caprivi. At the tsetse/cattle interface, the incidence of

bovine trypanosomosis is determined by the level of interaction between tsetse and cattle and is not necessarily correlated with the density of the tsetse population in the tsetse-infested area.

Determining the prevalence of bovine trypanosomosis accurately is fraught with difficulties. The parasitological diagnostic methods, that are commonly used, have low diagnostic sensitivity. Hence, a substantial proportion of the parasitologically positive animals will not be detected. This will result in an underestimate of the prevalence of infection. Therefore, the distribution of bovine trypanosomosis is determined best by combining parasitological diagnostic methods with methods that have higher sensitivity. The anti-trypanosmal antibody detection ELISA is a diagnostic test with high sensitivity and specificity. Furthermore, non-specific cross reactions with antibodies against common tick-borne parasites, such as *Anaplasma marginale* and *Babesia* spp., do not occur. Anti-trypanosomal antibodies are an indirect indication of a trypanosomal infection and persist up to 13 months after a trypanosomal infection has been treated successfully or has self-cured. Consequently, by using data on the prevalence of anti-trypanosomal antibodies, areas where trypanosomosis challenge is low, irregular or where trypanocidal drugs are used frequently can be identified.

An important determinant in the selection of priority areas for the control of bovine trypanosomosis is the effect of the disease on agricultural development. A usual consequence of a trypanosomal infection in susceptible cattle breeds is the development of anaemia. The level of anaemia is a good representation of the severity of the disease or the disease status of an infected animal. It is strongly correlated with the infected animal's performance. At the herd level, the herd average PCV decreases with increasing prevalence of trypanosomal infections. The shape of the relationship between herd average PCV and prevalence of trypanosomal infections, expressed by the slope of the regression line between average PCV and prevalence, is a useful indicator of (i) the impact of various levels of disease prevalence on herd health and (ii) the likely impact of control interventions on herd health. By establishing the slopes of the regression lines spatial and temporal comparisons can be made of the impact of trypanosomosis. On the plateau of eastern Zambia, for example, the impact of trypanosomal infections on herd average PCV is lowest in areas where challenge is

continuous and where tsetse feed mainly on cattle. Such conditions are conducive to the development of non-sterile immunity. In areas where challenge is irregular or where tsetse take a large proportion of their meals on game animals, the herd average PCV decreases significantly faster with increasing prevalence of trypanosomal infections. Season also plays an important role in determining the impact of trypanosomal infections on herd average PCV. During the dry season, when nutritional stress is highest, the decline in herd average PCV with increasing prevalence of trypanosomal infections is faster compared to the rainy season. The level and the effectiveness of trypanocidal drug treatments affect the direct socio-economic impacts of bovine trypanosomosis on animal production. In southern Africa, where trypanocidal drugs are readily available and where trypanocidal drug resistance is not widespread, mortality due to trypanosomosis is low and bovine trypanosomosis mainly reduces calving rates. The prevalence of the disease and the level of disease tolerance affect the reduction in calving rate due to the presence of the disease. The socio-economic impact of bovine trypanosomosis is generally highest in areas where cattle are kept adjacent to tsetse-infested zones such as the Vwaza area in the Northern Region of Malawi. All other, mainly indirect, impacts of bovine trypanosomosis 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 variables and their linkages 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.

Trypanocidal drugs are used widely in the southern African region. An analysis of drug-use practices has indicated that the majority of cattle owners prefer curative over chemoprophylactic drugs. Furthermore, cattle owners prefer to treat productive animals in the herd (oxen and cows) and appear to apply a production-oriented treatment strategy. This treatment strategy reduces the trypanosomosis-related mortality but has little effect on the calving rate. The sustainability of a drug-based trypanosomosis control strategy depends to a large extent on the drug-use practices. Survey results indicate that, even though farmers administer most trypanocides themselves, there is no evidence of frequent under-dosing and other factors enhancing the development of trypanocidal drug resistance were not present.

Odour-baited targets have proven to be an effective tsetse control method in large areas of homogenous vegetation. In relatively small, cultivated, areas also the presence of odour-baited, insecticide-treated targets at a density of approximately 4/km^2 results in a rapid decline in the tsetse population density and a reduction in the incidence of bovine trypanosomosis. Seasonal changes in the distribution of tsetse can be exploited by the deployment of targets in selected vegetation types. Targets are also effective barriers against the re-invasion of tsetse into cleared areas. Insecticide-treated cattle are a very effective means to control nagana in areas where tsetse take a large proportion of their blood meals from cattle. However, insecticide-treated cattle will only be effective when they sufficiently reduce the density of tsetse to reduce the incidence of bovine trypanosomosis. Insecticide-treated cattle do not constitute effective barriers against the re-invasion by tsetse. Even in the absence of an effect on the incidence of bovine trypanosomosis, insecticide treatments result in an immediate improvement of animal condition. This is best represented by the increase in the herd average PCV and is attributed to the effect of the insecticide-treatments on tick burden. Whereas the acaricidal effect of the insecticides to control tsetse may be beneficial in preventing tick-borne disease outbreaks, it may affect the development of enzootic stability. This is the case in eastern Zimbabwe where deltamethrin treatments at short intervals have resulted in a decline in the density of *Boophilus* spp. with a concomitant reduction in tick and *Babesia*-challenge and the development of an enzootic unstable situation.

Results of this thesis have shown that 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. The choice of a particular control method will depend largely on the local epidemiological situation. By distinguishing the different epidmiological situation in southern Africa and by analysing their characteristics, appropriate methods to control bovine trypanosomosis have been identified.

OPSOMMING

ONTWIKKELING VAN 'N NUWE STRATEGIE VIR DIE VOLHOUBARE BEHEER VAN TRIPANOSOMOSE VAN BEESTE IN SUIDER-AFRIKA

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Formulering van strategieë vir die grootskaalse uitroeiing van tsetsevlieë in Suider-Afrika is vroeër deur eenvoudige tegniese oorwegings oorheers. Met die huidige oorgang na gelokaliseerde beheer van tsetse-oorgedraagde tripanosomose van beeste verskuif die klem van die vektor na die siekte. Nagana is steeds die hoofrede vir ingryping, maar

beheermetodes verskil na gelang van die plaaslike situasie en beheer word slegs toegepas waar die siekte voorkom. Die tegniese kriteria wat oorweeg word verskil dus aansienlik van dié wanneer grootskaalse uitroeiing beplan word. Eerstens moet die omvang van die probleem vasgestel word. Tweedens hang die keuse van die mees doeltreffende beheermetode van die plaaslike epidemiologiese toestande af. Die onderskeie epidemiologiese toestande en die effektiwiteit van beheermetodes moet dus bepaal word. Laastens hang die langtermyn volhoubaarheid van ingryping grootliks af van die sosio-ekonomiese uitwerking van die siekte en die gewaande voordele van beheer.

Tsetse-oorgedraagde tripanosomose van beeste kom in groot gedeeltes van Malawi, Zambië, Zimbabwe en Namibië voor. Die epidemiologie van die siekte verskil aansienlik van plek tot plek. Op die plato van Oos-Zambië word beeste bv. in 'n tsetsebesmette gebied aangehou. Deurdat mense en hul beeste tsetsebesmette gebiede binnedring, daal die wildgetalle en word tsetse afhanklik van beeste as voedingsbron. Die verspreiding en bevolkingsdigtheid van tsetse word dus grootliks deur die verspreiding van beeste en veranderings in hul weipatroon bepaal. Die voorkoms van *Trypanosoma congolense*, die belangrikste spesie van beide tsetsevlieë en beeste, ondergaan min verandering van maand tot maand en word veral deur die ouderdom van die tsetsebevolking beïnvloed. Die voorkoms van nuwe tripanosomosegevalle by beeste is betekenisvol gekorreleer met die digtheid van die tsetsebevolking.

Tripanosomose van beeste kom ook algemeen voor waar beeste langs 'n tsetsebesmette gebied aangehou word of waar tsetsevlieë soms 'n tsetsevrye gebied binnedring. In Malawi grens die hoof besmettingshaarde van tripanosomose aan tsetsebesmette nasionale parke, wildtuine of bosreservate. Weens die seisoenale beweging van tsetse langs riviere of die voorkoms van klein kolle tsetse wat oor die hoof gesien word, kom tripanosomose van beeste ook ver buite bekende tsetsekolle voor. Voorheen onbekende tsetsekolle is later in Malawi en Zimbabwe opgespoor. In die meeste gebiede word tripanosomose deur *T. congolense* veroorsaak. Die voorkoms van *T. vivax* is egter hoog waar tsetse dikwels op wild voed, soos in die Mamiligebied van Oos-Caprivi. Die voorkoms van tripanosomose hang af van die vlak van interaksie tussen tsetse en beeste en korreleer nie noodwendig met die digtheid van die tsetsebevolking nie.

Dis moeilik om die voorkoms van tripanosomose van beeste akkuraat te peil. Die parasitologiese metodes wat algemeen gebruik word het 'n lae diagnostiese sensitiwiteit. Dit lei tot onderskatting van die voorkoms van besmetting. Die verspreiding van tripanosomose word beter deur 'n kombinasie van parasitologiese en meer sensitiewe metodes bepaal. Die anti-tripanosoom-teenliggaambepalende ELISA is uiters sensitief en spesifiek; nie-spesifieke kruisreaksies met teenliggame teen algemene bosluisoorgedraagde antigene soos *Anaplasma marginale* en *Babesia* spp. kom nie voor nie. Anti-tripanosoom-teenliggaampies, 'n indirekte aanduiding van besmetting, bly behoue tot 13 maande nadat 'n besmetting suksesvol behandel is of selfgenesing ingetree het. Deur die voorkoms van anti-tripanosoom-teenliggaampies vas te stel kan gebiede waar daging met tripanosome laag of ongereeld is of waar tripanosoomdodende middels dikwels gebruik word, bepaal word.

Die uitwerking van die siekte op landbou-ontwikkeling is 'n belangrike bepaler by die keuse van voorkeurgebiede om tripanosomose te beheer. Besmetting van vatbare beesrasse lei gewoonlik tot bloedarmoede; die vlak daarvan is 'n goeie aanduider van die felheid van die siekte of die siektetoestand van 'n besmette dier en is sterk gekorreleer met produksie. Op kuddevlak daal die gemiddelde gepakte selvolume (GSV) met stygende voorkoms van tripanosoombesmetting. Die verwantskap tussen gemiddelde GSV van 'n kudde en die voorkoms van tripanosoombesmetting, as regressielyn uitgedruk, is 'n handige aanduider van (i) die uitwerking van verskeie voorkomsvlakke op kuddegesondheid en (ii) die waarskynlike uitwerking van beheeringrepe op kuddegesondheid. Deur die hellings van regressielyne te bepaal kan ruimtelike en tydgebonde vergelykings van die uitwerking van tripanosomose gemaak word. Op die Oos-Zambiese plato is die uitwerking van tripanosoombesmetting op gemiddelde GSV van kuddes op sy laagste by ononderbroke daging en waar tsetse veral op beeste voed. Sulke omstandighede bevorder die ontstaan van nie-steriele immuniteit. Waar daging ongereeld is en tsetse veral op wild voed daal die gemiddelde GSV van kuddes betekenisvol vinniger met toenemende tripanosoombesmetting. Seisoen speel ook 'n belangrike rol by die bepaling van die uitwerking van tripanosoombesmetting op gemiddelde GSV van kuddes. Tydens die droë seisoen, met voedingstres op sy hoogste, daal gemiddelde GSV van kuddes vinniger as tydens die reëntyd. Die vlak en doeltreffendheid van behandeling met tripanosoomdodende middels beïnvloed die direkte sosio-ekonomiese effek van tripanosomose op produksie van beeste. In Suider-Afrika, waar dié middels geredelik beskikbaar is, is mortaliteit weens

tripanosomose laag en lei besmetting veral tot verlaagde kalfpersentasies. Die voorkoms van die siekte en die vlak van weerstandigheid beïnvloed die daling in kalfpersentasies. Die sosio-ekonomiese uitwerking van tripanosomose is die hoogste waar beeste langs tsetsebesmette gebiede aangehou word, bv. die Vwazagebied in die noordelike streek van Malawi. Al die ander, veral indirekte, uitwerkings van tripanosomose word deur nie-verwante faktore beïnvloed, bv. siektebestuur, die moontlikheid om kuddes en bewerkte grond uit te brei en die behoefte aan kontant. Al hierdie veranderlikes en hul onderlinge verwantskap moet in ag geneem word wanneer plaaslike beheer van tripanosomose van beeste beplan word. Versuim mag lei tot die oorberaming van die voordele van beheer en kan dus die volhoubaarheid van die ingreep beïnvloed.

Tripanosoomdodende middels word algemeen in Suider-Afrika toegedien. 'n Ontleding dui daarop dat die meerderheid beeseienaars genesende middels bo voorkomende middels verkies. Eienaars verkies ook om produktiewe diere (osse en koeie) te behandel en pas veral 'n produksegerigte behandelingstrategie toe. Dié behandeling verlaag vrektes weens tripanosomose maar het weining invloed op die kalfpersentasie. Die volhoubaarheid van 'n middelgebaseerde beheerstrategie hang grootlik van die gebruikswyse van die middels af. Alhoewel boere die meeste middels self toedien, toon ontleding van opnames dat onderdosering nie juis voorkom nie en dat ander faktore wat die ontwikkeling van middelweerstand bevorder, ontbreek.

Teikens met geur as lokmiddel is 'n doeltreffende tsetsebeheermetode in groot gebiede met 'n eenvormige plantegroei. In relatief klein, bewerkte gebiede het sulke teikens, met insekdoders behandel, teen 'n digtheid van sowat 4/km^2 gelei tot 'n vinnige afname van die tsetsebevolking en 'n daling in die voorkoms van tripanosomose. Seisoenale veranderings in die verspreiding van tsetsevlieë kan uitgebuit word deur teikens in geselekteerde plantegroeitipes uit te plaas. Teikens is ook 'n doeltreffende versperring teen die herbesmetting van skoongemaakte gebiede deur tsetsevlieë. Beeste wat met insekdoders behandel is, is 'n belangrike metode om nagana te beheer in gebiede waar tsetse veral op beeste voed. Sulke beeste is egter slegs doeltreffend indien hulle die tsetsedigtheid genoegsaam verlaag om die voorkoms van tripanosomose te laat daal. Beeste wat met insekdoders behandel is, is onvoldoende om herbesmetting van 'n gebied deur tsetsevlieë te verhoed. Selfs waar daar geen effek op die voorkoms van tripanosomose is nie, lei

behandeling van beeste met insekdoders dadelik tot 'n verbetering in hul kondisie. Dit word weerspieël deur 'n styging in die kudde se gemiddelde GSV en word toegeskryf aan die middel se uitwerking op die bosluislading. Alhoewel die bosluisdodende effek van insekdoders voordelig mag wees om uitbreke van bosluisoorgedraagde siektes te voorkom, kan dit die ontstaan van ensoötiese stabiliteit beïnvloed. Dit het in Oos-Zimbabwe gebeur, waar deltametrienbehandeling met kort tussenposes tot 'n verlaging in die bevolkingsdigtheid van *Boophilus* spp. en dus in bosluis- en *Babesia*-daging gelei het; 'n ensoöties onstabiele toestand was die gevolg.

Die resultate van hierdie proefskrif toon dat beplanning vir die volhoubare beheer van tripanosomose van beeste op plaaslike vlak 'n multidissiplinêre oefening is wat 'n grondige begrip van die verspreiding en epidemiologie van die siekte verg. Die keuse van 'n bepaalde beheermetode hang grootliks af van die plaaslike epidemiologie van die siekte. Deur die verskeie epidemiologiese toestande in Suider-Afrika te onderskei en hul eienskappe te ontleed, is toepaslike metodes om tripanosomose van beeste te beheer geïdentifiseer.

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INTRODUCTION

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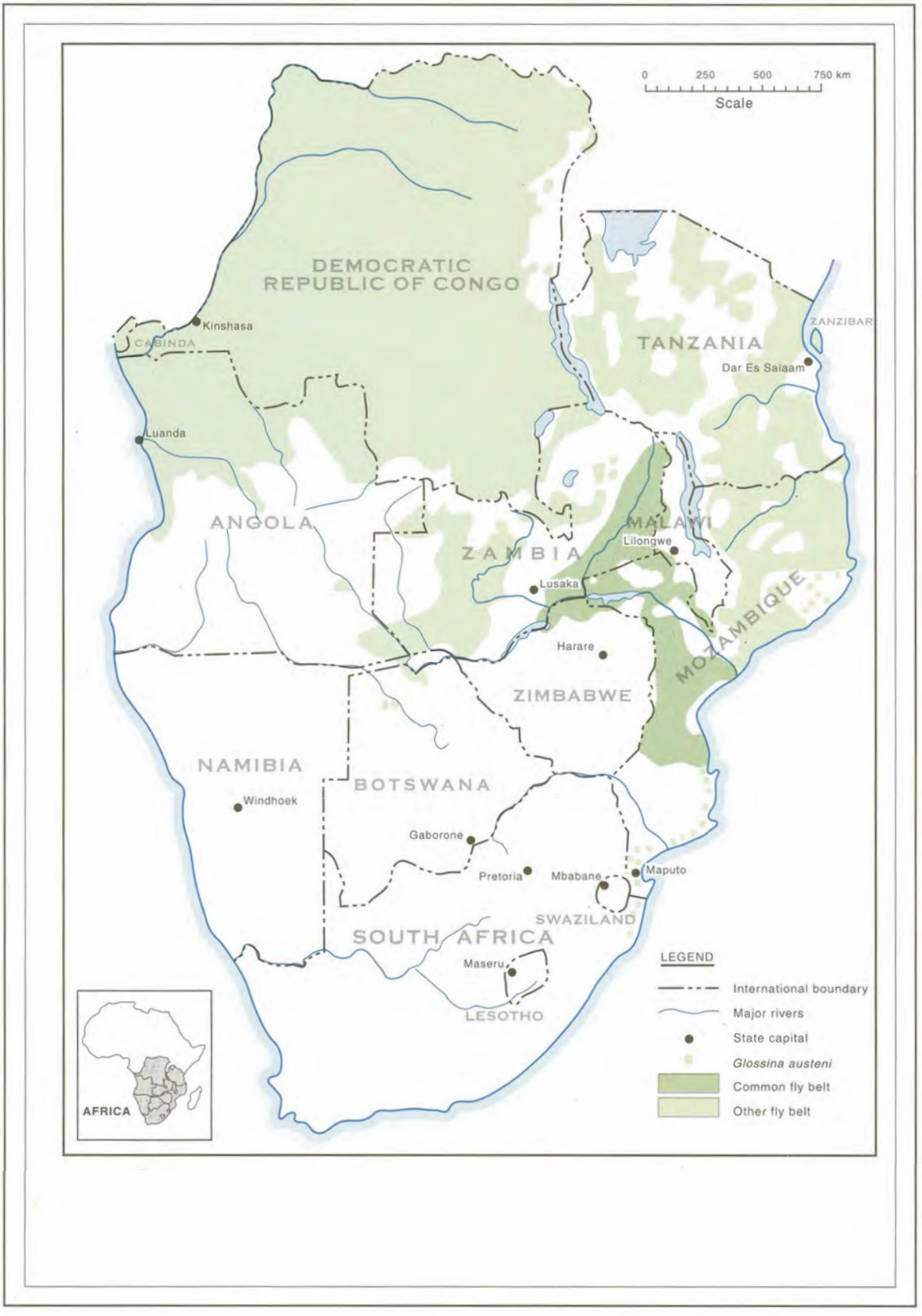

Tsetse-transmitted trypanosomosis is recognized widely as a major animal disease particularly, but not exclusively, in sub-Saharan Africa (Jordan, 1986). In the majority of 37 sub-Saharan countries affected by tsetse-transmitted trypanosomosis, the problem is classified as severe and ranks among the three top priority livestock diseases. Approximately seven million km^2 of the tsetse-infested areas would probably be suitable for livestock and agricultural development if trypanosomosis were controlled (Finelle, 1974).

In Malawi, Eastern Caprivi region of Namibia, eastern Zambia and Zimbabwe (the countries dealt with in the thesis and henceforth referred to as southern Africa), trypanosomosis poses a serious threat to cattle. Bovine trypanosomosis or "nagana" depresses all aspects of production: fertility is impaired; milk yields, growth and work output are reduced; and the mortality rate may reduce herd size (Connor, 1994a). Therefore, bovine trypanosomosis is a significant factor responsible for retarding rural development in much of southern Africa.

There are various ways of dealing with the bovine trypanosomosis problem (Jordan, 1986). They range from eradication of the vector, the tsetse fly, to treating trypanosomal infections with therapeutic drugs. In much of southern Africa, however, trypanosomosis control has focused on the large-scale control of the vector with the ultimate aim of its eradication (Jordan, 1985).

Throughout the long history of tsetse control in southern Africa impressive progress has been made in the development of effective means of controlling the fly (Vale, 1993b; Green, 1994). Tsetse control has evolved from indirect methods, such as altering the tsetse's environment, to direct methods using toxic substances (Allsopp, 1984). Applying a variety of methods, governments (sometimes assisted by donors) have been able to clear large areas of tsetse (Lovemore, 1986; Shereni, 1990). Unfortunately, very few countries have been able to sustain those reclamations. This is attributed to re-invasion by tsetse of cleared areas in the absence of permanent barriers (such as natural barriers) to tsetse invasion and the ineffectiveness of most tsetse control methods in preventing tsetse from re-invading cleared areas. In recent

years, new methods to control tsetse have been developed and these greatly improve the prospects for effective barriers against tsetse re-invasion (Muzari and Hargrove, 1996).

Despite the availability of effective tsetse control methods, however, the prospects for large-scale control of the vector are bleak. Due to the unfavourable economic situation in most African countries, costs involved in the large-scale control of tsetse and subsequently maintaining artificial barriers against re-invasion have become prohibitive. Nevertheless, bovine trypanosomosis is and will remain a serious constraint to rural development. This will be more so when tsetse-infested land is required to settle a continuously expanding human population (Hursey, 1998). There is thus a need to re-orient planning for the control of bovine trypanosomosis in line with the changing environment.

The current unfavourable economic environment has prompted a shift in emphasis from government/donor-funded, large-scale, tsetse control to small-scale, sustainable, trypanosomosis control. This shift reflects, in part, the reduction in government capacity and change in government's policy towards the control of endemic diseases such as trypanosomosis but also the changing attitude of donors towards more participatory and sustainable approaches (Umali *et al.*, 1994). This change from eradication of the vector, towards small-scale sustainable control has important implications for strategy formulation, which is a dynamic process that identifies, ranks and constantly adjusts priority areas for such sustainable trypanosomosis control. It addresses the following questions:

- *Why*?: The need for control should be established at the outset. Objectives should always be directed towards removing or alleviating the problems and constraints associated with trypanosomal infections. At the same time, the potential to create new problems should be recognised.
- *How*? : The effectiveness, transferability and sustainability of different control methods should be properly assessed. When communities are involved in control

operations, it is particularly important to evaluate the transferability and sustainability of the methods proposed.

- *When*?: Implementation schedules should be based on realistic assumptions about the availability of labour, management and financial resources. During planning, it may be necessary to quantify resource constraints at different levels (e.g. at the government, community and/or small holder levels).
- *Where*?: Priority areas for control operations must be identified and then ranked.
- *By whom*?: Responsibilities for the implementation and maintenance of control operations should be stated. Government, private contractor and/or community responsibilities must be clearly defined and understood by those involved.
- *For what benefits and costs*?: The direct and indirect benefits and costs of any proposed operation should, where possible, be identified and quantified. The hidden effects and potential conflicts associated with the implementation of control operations should be carefully considered as well.
- *Paid for by Whom*?: Financial responsibilities for control operations should be defined for the short, medium and long term.

To address these questions properly, potential control options should be screened by considering carefully socio-economic, institutional, technical and environmental criteria. A failure to consider adequately these different criteria can result in problems, which will undermine the sustainability of an intervention.

It is beyond the scope of this thesis to consider all of the above mentioned criteria. However, two of them, the technical and socio-economic ones, will be looked at in more detail.

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 technical efficiency of an eradication campaign did not require a thorough knowledge or understanding of, for example, the distribution and epidemiology of tsetse-

transmitted bovine trypanosomosis. Notwithstanding the fact that nagana was the main reason for intervening, the disease itself would be dealt with indirectly by eradicating the vector from all areas including those where nagana was not present. The current shift to localised control of tsetse-transmitted bovine trypanosomosis has changed the emphasis from the vector to the disease. Nagana remains the main reason for intervening but control methods will differ according to the local situation and interventions will be restricted to those areas where the disease is present. As a result, the technical criteria to be considered will differ substantially from those considered in the planning for large-scale eradication. First, a clear picture of the extent and magnitude of the bovine trypanosomosis problem is required. Second, the selection of the most efficient intervention methods will vary according to the local epidemiological situation. Hence, the different epidemiological situations need to be identified and the effectiveness of available control methods needs to be evaluated in each of these situations. This will require an understanding of the numerous variables involved in the epidemiology of nagana in southern Africa. Finally, the long-term sustainability of an intervention will depend, to a large extent, upon the socio-economic impact of the disease and perceived benefits accruing from its control. Hence, the socio-economic impact of the disease and the determining factors need to be assessed and identified.

The epidemiology of tsetse-transmitted bovine trypanosomosis is complex (Rogers, 1988). Detailed information is available on the behaviour of most southern African tsetse species of economic importance (Phelps and Lovemore, 1994). Nevertheless, there is insufficient knowledge of the fly-related variables that determine the interaction between *Glossina morsitans morsitans*, the major vector of bovine trypanosomosis in southern Africa, and cattle. Data available on, for example, the seasonal distribution and abundance of this tsetse species and factors affecting those variables were collected in wildlife areas that cannot be compared with areas where the cattle/tsetse interface occurs (Pilson and Pilson, 1967). Moreover, *G. m. morsitans* populations have been investigated using sampling methods of unknown sensitivity and different sampling biases (Bursell, 1961). Although the epidemiology of trypanosomal infections in *G. pallidipes* has been investigated thoroughly

(Woolhouse *et al.*, 1993; Woolhouse *et al.*, 1994), too little information is available on the prevalence of trypanosomal infections in *G. m. morsitans*. More studies are thus required on the epidemiology of bovine trypanosomosis in southern Africa.

Accurate and up-to-date information on the distribution and prevalence of tsetse-transmitted bovine trypanosomosis in southern Africa is sparse. Moreover, the little information that is available has been collected using methods of low sensitivity (Paris *et al.*, 1982). This leaves many areas where trypanosomosis is present but unidentified. In areas where the disease has been detected, the magnitude of the problem is likely to be quantified poorly and underestimated. Hence, available information on the distribution is an unreliable source for the development of a strategy for sustainable localised control. The recent development of a more sensitive and practical indirect method (anti-trypanosomal antibody detection enzyme-linked immunosorbent assay (antibody ELISA)) to detect the presence of bovine trypanosomosis (Hopkins *et al.*, 1998), offers the possibility of determining more accurately the distribution of the disease. Unfortunately, the usefulness of this indirect method has not yet been fully assessed and interpretation of results needs to be improved.

Entomological and veterinary data rather than socio-economic principles formed the backbone for planning large-scale tsetse control or eradication campaigns. Socio-economics were only considered when improving the cost-effectiveness of control methods (Vale, 1993b; Barrett, 1994). Similarly, the impact of control interventions has been measured using entomological and veterinary indicators rather than socio-economic ones. As a result, little is known of the socio-economic impact of bovine trypanosomosis and its control on cattle productivity. Socio-economic aspects of the impact of the disease and expected impact of control interventions, on the other hand, form an essential component of planning for cost-effective control. From a socio-economic point of view, sustainable control can only be achieved when the benefits accruing from the control intervention are larger than its cost (Salmon and Barrett, 1994; Swallow and Woudyalew, 1994). There is thus a need to assess carefully the impact of bovine trypanosomosis on the productivity of cattle. Moreover, the

relationship between trypanosomosis, at various levels of disease prevalence, and productivity needs to be established.

Today, two tsetse control methods, based on bait technology, are used increasingly and more widely in southern Africa. Stationary baits (odour-baited, insecticide-treated, targets (Vale *et al.*, 1986)) have proven to be very effective in controlling tsetse in large, homogenous areas (Vale *et al.*, 1988a; Knols *et al.*, 1993). The effectiveness of this method in controlling tsetse in small, cultivated areas still needs to be assessed. The effectiveness of mobile baits (insecticide-treated cattle (Thomson, 1987)) in controlling tsetse or reducing tsetse challenge, under conditions prevailing in southern Africa, still needs to be tested. The effects of applying insecticide to cattle on tick challenge and the development of enzootic stability against some tick-borne diseases need to be determined. Moreover, the role that insecticide-treated cattle could play in preventing tsetse from re-invading previously cleared areas still has to be assessed. Despite the rather superficial knowledge of the effectiveness of these methods in the small-scale control of tsetse or in preventing the spread of tsetse, both methods are promoted widely. There is a need to investigate more thoroughly the effectiveness and socio-economic impact of these control method under different circumstances.

An alternative to the control of tsetse is the control of trypanosomosis with drugs (Peregrine, 1994). In most countries of southern Africa, farmers are able to buy trypanocides and can thus implement their own disease management strategies using therapeutic or prophylactic drugs. The long-term sustainability of such an approach is a function of the probability of trypanosomes developing resistance against those drugs (Geerts and Holmes, 1997). Trypanocidal drug resistance has been recorded in many countries in West and East Africa (Pinder and Authié, 1984; Dolan *et al.*, 1992). In southern Africa, little is known of the susceptibility of trypanosome strains to trypanocidal drugs. Sensitive methods to determine the susceptibility of trypanosomes to isometamidium chloride (the principal prophylactic trypanocide) have been developed and are being used on a trial basis (Eisler *et al.*, 1996). Unfortunately, those techniques are expensive and cannot be used to assess the susceptibility of

trypanosome strains to the most commonly used, therapeutic trypanocide, diminazene aceturate. A first step in determining the probability of drug resistance could be the establishment of the frequency with which trypanocides are used, the dose and the mode of application. This simple information is not available but could be collected during surveys. Results of such "drug use" surveys should form an integral part of the decision-making process on how to control trypanosomosis in a particular area.

Finally, the sustainability of a disease control intervention will to a large extent be determined by the cattle owner's attitude towards his animals. Although this information is difficult to quantify, data on trypanocide use could be used as an indirect and quantifiable indicator of this attitude.

By collecting the required information and improving the interpretation of the results, a significant contribution will be made 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.

The specific aims of the investigations outlined in this thesis were:

1. *to obtain a better understanding of the interaction between tsetse and cattle in an area in southern Africa where tsetse-transmitted bovine trypanosomosis is endemic (Chapter 2);*

2. *to use improved methods to update distribution maps and improve the understanding of the epidemiology of bovine trypanosomosis in southern Africa (Chapter 3);*

3. *to assess the impact of bovine trypanosomosis on production and agricultural development in southern Africa (Chapter 4);*

4. *to investigate trypanocidal drug use and the impact of various tsetse control methods, under different epidemiological situations, in the southern Africa (Chapter 5).*

The findings obtained from these studies indicate that planning for the effective control of tsetse-transmitted bovine trypanosomosis in southern Africa requires an understanding of the dynamics of the tsetse population and accurate knowledge of the distribution of the disease, its impact on production and productivity, and the impact of control interventions under various epidemiological situations.