

**History of the development, use and impact of tsetse control measures in Zimbabwe**

**By**

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Doctor of Philosophy in Veterinary Science Veterinary Tropical Diseases  
in the Department of Veterinary Tropical Diseases,  
Faculty of Veterinary Science, University of Pretoria, South Africa**

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## **DEDICATION**

I dedicate this thesis to my family, especially to my daughter, Carol Shereni, for their encouragement and support during my studies.

## **DECLARATION**

I hereby declare that this thesis is my own work. It is submitted in fulfilment of the Doctor of Philosophy at the University of Pretoria, South Africa. It has not been submitted before for any degree or examination in any other University.

**William Shereni**

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## List of acronyms

AAT	Animal African trypanosomiasis
ANOVA	Analysis of variance
AW-IPM	Area-Wide, Integrated Pest Management
BBC	British Broadcasting Corporation
DDT	Dichlorodiphenyltrichloroethane
DVFS	Division of Veterinary Field Services
EC	Emulsifiable concentrate
ELISA	Enzyme-Linked Immunosorbent Assay
EU	European Union
FAO	Food and Agriculture Organization
GPS	Global Positioning System
HAT	Human African trypanosomiasis
HQ	Headquarters
IAEA	International Atomic Energy Agency
IPMI	International Pest Management Initiative
ITC	Insecticide treated cattle
ITT	Insecticide treated targets
OIE	World Organisation for Animal Health
PATTEC	Pan African Tsetse Trypanosomiasis Eradication Campaign
PCP	Progressive Control Pathway
PCR	Polymerase Chain Reaction
RTTCP	Regional Tsetse and Trypanosomiasis Control Programme
SADC	Southern Africa Development Committee
SAT	Sequential aerosol technique
SC	Suspension concentrate
SEMG	Scientific Environmental Monitoring Group
SIT	Sterile Insect Technique
SNS	Specialized National Structure
T&T	Tsetse and Trypanosomiasis
TCD	Division of Tsetse Control Services
TRL	Tsetse Research Laboratory
TTCB	Tsetse and Trypanosomiasis Control Branch
WHO/TDR	World Health Organization / Tropical Disease Research

WP

Wettable powder

## **THESIS SUMMARY**

### **History of the development, use and impact of tsetse control measures in Zimbabwe**

by

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This study evaluated the impacts of different control techniques on tsetse and animal African trypanosomiasis (AAT). To appreciate the selection and use of different control measures under different circumstances, it was necessary to understand the sequence of how the techniques were developed, and why. That sequence was assisted by progressive refinements in knowledge of the behaviour, ecology and physiology of tsetse.

The choice of techniques to apply depended mainly on the objective of the control programme and predictions for cost-effectiveness and environmental impact. Using specific case studies, present work evaluated the performance of different control techniques by their effects on the abundance and distribution of tsetse and the prevalence of AAT. Consideration of the numerous field operations conducted since 1980 offered important lessons on how the different techniques should be applied to best advantage.

Epidemiological and entomological data are important aids to the design of control programmes. There is, therefore, a need to ensure that such data are stored in a centralized and harmonized information system, i.e. an atlas. This information system is key in the identification and prioritisation of areas for tsetse control interventions. Atlas data were used in developing the Progressive Control Pathway (PCP), which categorises areas for attention in specific stages of the PCP. It is expected that the PCP will be instrumental in informing

policy and designing strategies for the elimination of AAT, in line with the OIE standards on the declaration of disease free status.

**Key Words:** Control measures, tsetse, AAT, PCP, atlas

## General Introduction

Tsetse (Diptera: Glossinidae) are vectors of the protozoan parasites which cause trypanosomiasis, a zoonotic disease that affects both humans and livestock (Buxton, 1955). Trypanosomiasis is endemic in Zimbabwe and the disease is known as animal African trypanosomiasis (AAT) or nagana in livestock and human African trypanosomiasis (HAT) in humans (Shereni *et al.*, 2016). Agriculture is the backbone of the Zimbabwean economy and livestock losses due to AAT continue to reduce the 35-38% contribution of cattle to the national Gross Domestic Product (FAO, 2019). HAT cases in Zimbabwe have been confined to the Zambezi Valley, North of the country. Since 2005, 32 cases and 3 HAT related deaths have been reported (WHO, 2020). Curative and prophylactic drugs are available for AAT, however, no vaccines or preventative drugs are available for sleeping sickness (Simarro *et al.*, 2010). To reduce the effects of trypanosomiasis, it is essential to eliminate tsetse from 31 000 km<sup>2</sup> currently infested, and create defense barriers to stop reinvasion into cleared areas (Shereni, 1990).

The development of tsetse control techniques provided a wide range of options as game elimination, bush clearing, ground spraying, sequential aerosol technique (SAT) and bait technology which were used in tsetse control programmes. Refinement in some techniques resulted in the abandonment of others, for example, bush clearing replaced game elimination, which in turn was replaced by ground and aerial spraying techniques following the advent of insecticides in the 1940s (Lovemore, 1994). Research at Rekomitjie (Vale, 1971) and Lusulu (Vale and Cumming, 1976) provided guiding principle in the application of ground spraying and selective game elimination to control tsetse. In view of the drawbacks associated with ground and aerial spraying it became necessary to conduct research into more environmentally- friendly and cost effective tsetse control options. It was in this context that investigations at Rekomitjie led to the development of artificial and live baits i.e. insecticide treated targets (ITT) (Vale *et al.*, 1984, 1986, 1988) and insecticide treated cattle (ITC) (Thompson, 1987). Stakeholders from the private sector facilitated the refinement of ITC, in the late 1980s, which today is regarded as the simplest and cheapest tsetse control technology (Barrett, 1997).

Before 1896 more than half (200 000km<sup>2</sup>) of the country was tsetse-infested. Changes in tsetse densities and distribution over the past twelve decades can be attributed to a wide range of factors including rinderpest outbreak of 1896 (Lovemore, 1994), application of tsetse

control technologies, anthropogenic factors and climate change. Among these factors, tsetse control has largely contributed to the decline in tsetse populations in Zimbabwe. Tsetse control in Zimbabwe was initiated in 1919 (Lovemore, 1994). In the 1980s, operations in NW and NE Zimbabwe involved the application of ground spraying, aerial spraying, ITT and ITC as a “mosaic” in integrated control programmes while targets and ground spraying were used in the North and ground spraying in the South East. Due to its adverse environmental effects (Cockbill, 1975; DFID, 1998) the use of DDT in ground spraying operations was discontinued in 1990. Post- independence application of SAT (Hursey and Allsopp, 1983) and successive progressive sprays, 1982-1986, led to the reclamation of extensive areas in NW and NE until 1988, when the technique was last used in Zimbabwe. Operations in NE Zimbabwe were, since 1986, implemented under the auspices of the EU funded, Regional Tsetse and Trypanosomiasis Control Programme (RTTCP) and resulted in the clearance of tsetse from 20 000km<sup>2</sup>. This programme ended in 2000. The turn of this millennium, saw a decline in donor funded projects although co-operating partners including the Pan African Tsetse Trypanosomiasis Eradication Campaign (PATTEC), World Health Organisation– Tropical Disease Resources (WHO-TDR), International Atomic Energy Agency (IAEA) and the Food Agriculture Organisation (FAO) continued to support tsetse control and research in Zimbabwe.

Over the years, harmonization of tsetse control data to produce a central information system was non-existent. Information was available in physical entomological sheets and over the years vital data pertaining to tsetse control operation was lost in fires, misplacing and misfiling. To minimize further loss of data, the concept of an Atlas (Cecchi *et al.*, 2015), which is a compilation of all tsetse and animal trypanosomiasis data into a harmonized database, developed by the FAO was adopted. This database can be used for different purposes including production of presence/absence and density maps that are essential for the development of the Progressive Control Pathway (PCP). Zimbabwe is in the process of developing its PCP for AAT. The PCP is a stepwise approach in the control of AAT from below stage1, when a country is at the stage of developing capacity to control the disease to stage 5, when a country has eliminated the disease.

### **Thesis Rationale**

The study will highlight the importance of applied research in the development of control techniques. Development of tsetse control techniques was based on the knowledge of tsetse

behavior, ecology and physiology. The study will also chronicle, application of the various tsetse control techniques from the 20<sup>th</sup> to 21<sup>st</sup> century and attempt to assess their impact. The study will highlight the importance of a centralized information system in handling tsetse and AAT data in order to make informed decisions. Regular updating of occurrence and distribution maps for tsetse and AAT from the atlas data will enable early detection of tsetse infestation and disease outbreaks. This will enable Tsetse Control Services to respond early before human and animal fatalities occur. The PCP for AAT will be a great tool in categorizing past and present T&T affected zones into the various stages, based on data on AAT recorded and control interventions implemented.

### **Research Questions**

1. What was the role of research in the development of tsetse control techniques
2. What impacts have the different control interventions had in efforts to eradicate tsetse and eliminate AAT
  - 2.1 What are the key lesson learnt from application of various tsetse control measures in different areas
3. What is the importance of a centralized information system in the data management of tsetse and AAT data
  - 3.1 How has Zimbabwe progressed in the control of AAT in accordance with the PCP categorization methodology

### **Thesis Objectives**

#### ***General Objective***

To demonstrate the role of research in the development of tsetse control measures, application of these measures in the control of tsetse and AAT, and collation of data into a centralised information system to support the development of a progressive control pathway.

#### ***Specific Objectives***

1. To assess the impact of tsetse research on the development of control measures
2. To assess impacts of the different control methodologies on tsetse and AAT from 1980- 2019.
  - 2.1 To determine appropriateness and limitations of control measures to varying tsetse habitats.

3. To develop a centralised information system for tsetse and AAT using data compiled during the last 2 decades (2000-2019).
- 3.1 To map out the spatio-temporal distribution of tsetse and AAT, determine tsetse apparent densities across the fly belt and AAT prevalence for the period 2000-2019.
- 3.2 Self-Assessment of the country's capacity to control AAT and the delineation of tsetse-transmitted AAT affected zones into the different PCP stages for AAT.

## **Hypotheses**

### ***Research Hypotheses***

1. Empirical evidence will be produced to demonstrate the development of various control techniques in Zimbabwe
2. Application of tsetse control techniques will impact on tsetse populations and trypanosomiasis prevalence
3. Vector and disease data can be harmonized to produce a central information system for the period 2000-2019
- 3.1 Presence/Absence maps for tsetse and AAT will be produced as well as tsetse apparent densities and AAT prevalence maps
- 3.2 A PCP map will be produced to show progress made toward elimination of AAT in Zimbabwe

## **Limitations /Delimitations of the study**

In this study a number of limitation were encountered

1. Research studies towards development of tsetse control techniques were mainly confined to Rekomitjie
2. Inconsistent sampling of the national herd for AAT
  - AAT sampling was erratic partly due to competing demands on other specified diseases and resource constraints
3. Non-randomized blood sample collection system during inspections for AAT
4. Some of the traps were not Geo-referenced
  - At least 1% of some traps used during the study did not have geographical coordinates and duplication of trap codes for example, different traps named A1
  - Same location with different names and inconsistent coordinates for the same trap making it appear like different traps
5. Attractants were sometimes used singly than in combination

6. Traps with different trap collectors and cloth materials were sometimes used
7. Some of the information was lost in the archives

### **Assumptions**

The researcher will assume that;

- Requisite information on control measures is extracted to study effects of these parameters on tsetse and trypanosomiasis
- Data for the creation of Atlas of Tsetse and AAT processed and related to data control.

### **Statement of the problem**

There is a gap existing in literature on how past research was applied in the development of control measures. A great deal of research was conducted in the past although no attempt has ever been made to compile a detailed chronological account of these works. The identification of high risk priority intervention areas was more difficult in the absence of a comprehensive centralised and harmonised database. In order to understand how control has impacted on the tsetse and trypanosomiasis problem, the study will focus on spatio-temporal changes in tsetse populations and occurrence of trypanosomiasis in relation to the various control interventions. Application of the PCP concepts will facilitate a step-wise approach in which high risk areas will be prioritized in the implementation of future control programmes. It is against this background that the researcher felt compelled to carry out the study.

In the absence of a centralized information system, it has been difficult to track and assess the level of success of operations conducted with various levels of control. A centralized information system (Atlas) will be developed in order to bring all the data into one system to address the challenges of conducting analyses. Despite efforts in the control of tsetse, there is a serious lack of documented literature to demonstrate success achieved in the past. Knowledge gap exists on the effectiveness/impact of different control techniques on the distribution and abundance of tsetse, and on the epidemiology of trypanosomiasis.

### **Significance/ purpose of the study**

The study is intended to provide valuable information on the impacts of various control techniques on the abundance and distribution of tsetse and transmission patterns of trypanosomiasis. Based on the development of a National Atlas for tsetse and

trypanosomiasis, the study will highlight the importance a centralized information system in handling T&T data in order to make informed decisions. The PCP for AAT will be used to inform national T&T policy and strategies to implement.

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## **Chapter 1 : Development of control measures**

## **1.1 Introduction**

The history of the application of tsetse control measures can be explained only by understanding the history of the successive development and improvement of the various methods, and the forces that led to their development. To provide the necessary background, it is required to go right back to the start of tsetse control and research in Zimbabwe to see what initiated it.

### **1.1.1 Early History**

#### **1.1.1.1 Initial development of game elimination**

The obvious method of control to try first was the destruction of wildlife, in simulation of the effects of rinderpest. An experiment to test the efficacy of this method, first test in Africa, began against *Glossina morsitans morsitans* Westwood (1905) (*G. m. morsitans*) in the Shangani and Gwai drainages in 1918, following a conference on tsetse control held in 1919 (Lovemore, 1994). A wide range of mammals were killed, on the knowledge that tsetse depend entirely on mammalian blood for their survival (Jack, 1914, 1939). Operations were confined to specific corridors, 16 km to 30 km wide (Hargrove, 2003), that were intended to be barriers to tsetse invasion. This work did not get rid of all tsetse hosts (Lovemore, 1963; Child and Wilson, 1964) and a few tsetse broke through the barriers.

Nevertheless, the technique of game elimination was subsequently adopted widely, as for example in Doma between 1924-1940; Chegutu between 1926-1940 and Makonde between 1931-1940. However, the pros and cons of this control measure were hotly debated between the government, local settlers and conservationists. Many persons outside the government regarded the destruction of wildlife as too damaging ecologically, while the professional and sporting hunters believed that if anybody should hunt it was they who should do it. The official position was that ranching interests were paramount so that the extermination of the wild animals was justified. However, all parties agreed that the aim should not be the complete destruction of the country's fauna. Hence, as a compromise, the official programme of wildlife destruction was supplemented by game conservative measures and authorised free shooting in certain areas (Pilossof, 2016). The outcome was that between 1890 and 1953 millions of game animals were exterminated to create a host-free zone to prevent European land or farms being invaded by tsetse from wilderness and conservation areas (Mutwira, 1989).

### **1.1.1.2 Royal Commission**

The Royal Commission was formed in 1937 with the aim of developing environmentally friendly techniques to tackle tsetse and trypanosomiasis constraints in Rhodesia (Zimbabwe) and Nyasaland (Zambia) was formed. Following the end of the World War II in 1945, the wholesale slaughter of so many wild animals became increasingly unacceptable (White, 1955; Ford, 1971). The Commission delivered its report in 1939, which recommended the cessation of wildlife destruction and urged the development of new techniques that were more ecologically suitable (Thomas, Davey and Potts, 1955), and/or the use of alternative methods that had been developed in other countries. These other methods were mainly bush-clearing (Ford, 1971), and aerial spraying (TTCB, 1971) or ground spraying (Cockbill, 1968; Robertson and Kluge, 1968) with organochlorines. The efficacies of all techniques were investigated, along with attempts to make host destruction more selective and hence more acceptable.

Use of trapping to catch-out the tsetse population was not then of stand-alone interest, although the Harris trap had been employed to supplement wildlife destruction in Zululand (Harris, 1938). However, traps of this and many other designs (Swynnerton, 1933; Morris and Morris, 1949) methods were regarded mainly as survey tools, to supplement the “flyround” technique which was regarded as the sampling method of choice in Zimbabwe and most other places (Buxton, 1955). This technique involved the handnet capture of tsetse attracted to parties of walking men, who sometimes carried screens of black cloth to enhance the catches.

The following describes the various considerations and investigations that were spurred in large part, directly or indirectly, by the report of the Royal Commission. Much of the research involved small-scale field studies in the Zambezi valley, at Rekomitjie Research Station, which was founded for that purpose in the late 1950s. Other work was performed at other places from time to time, often on larger scales, for example, the selective host elimination and its refinement through bloodmeal experiments in Nagupande and Sengwa.

### **1.1.1.3 Bush clearing**

It is necessary to recognise two sorts of bush clearing, as below.

#### *Total clearing*

According to Ford *et al.*, (1970) ‘Total, sheer or ruthless clearing means the destruction of all trees and shrubs in the area treated. It is a completely effective method of eliminating tsetse, and the oldest’. However, the effects of bush clearing as an anti-tsetse measures are extremely difficult to distinguish from the effects of game destruction. This is because the complete obliteration of the vegetation not only destroys the essential habitat of tsetse, it also reduced the abundance of hosts (Hargrove, 2003). Thus, the use of total clearing was hardly preferable to the wholesale eradication of hosts.

#### *Partial, selective and discriminative clearing*

Selective clearing involved partial removal of particular species of vegetation, whereas discriminative clearing is the removal of all woody vegetation from particular plant communities (Ford, 1970). Both types of clearing are aimed at destroying the essential woodland habitat of the flies. The concept of essential habitat was based partly on a series of mark-recapture studies of tsetse dispersal in East Africa, (Jackson, 1941, 1944, 1948). It was observed that the rate at which tsetse dispersed away from the release point decreased the longer the dispersal time. It was suggested to Jackson by R.A Fisher, the famous statistician, that the results showed that tsetse made directed movements between two types of habitats. The proposed types were: (i) a “home” consisting of woodland, which the flies vacated only temporarily, and (ii) more open “feeding grounds” where hosts were easier to find but which were inadequately wooded for the long term survival of tsetse. The notion of essential habitat was reinforced by the fact that flyround catches were by far the greatest in semi-evergreen riverine woodland during the hot dry season, suggesting woodland was especially important for fly survival at that time.

Despite the seemingly sound theories in favour of limited bush clearing, the development of the technique was abandoned in the late 1970s (Lovemore, 1994). This was because the technique was ecological destructive and was more expensive and less effective than the developing technology of ground spraying.

#### 1.1.1.4 Development of Ground Spraying

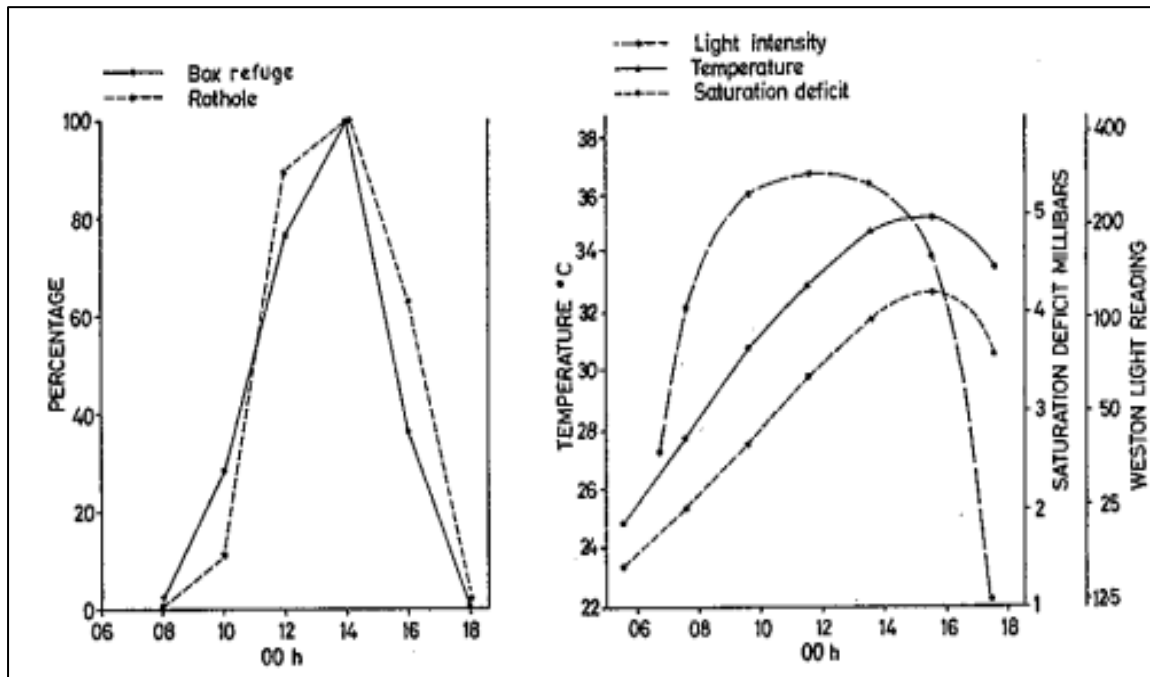
The above indications for the potential efficacy of clearing woodland suggested that ground spraying would be most cost effective if it were applied primarily to riverine woodland in the hot dry season. The general plan was to spray residual insecticide to the resting places of tsetse in the riverine areas in the cool dry season. The insecticide was believed to become effective when the flies concentrated there in the hot dry season. It was accepted that the insecticide would be washed away in the rainy season. There were four main aspects to the development of ground spraying: i) which sorts of resting sites should be targeted for spraying, ii) elucidation of whether the flies really were confined to the riverine "home" in the hot dry season, iii) what sort of insecticide should be used, and iv) getting the logistics right.

##### *i) What resting sites should be sprayed and where?*

There had already been some studies of the resting sites of *G. swynnertoni* Aust. in Tanzania, East Africa (Isherwood, 1957). To supplement this, Pilson and Leggate started diurnal and seasonal studies of resting behaviour of *Glossina pallidipes Austeni* (*G. pallidipes*) in 1959, in the riverine vegetation at Rekomitjie, in combination with studies of feeding behaviour (Pilson and Leggate, 1962a, 1962b). Fully-fed flies caught on a stationary ox were marked and released and their subsequent resting places were recorded. During the rainy season (February), the cool season (May) and the early dry season (August), the day-time resting sites were almost exclusively on branches. Flies appeared to rest largely on leaves and small twigs at night. However, in the middle of the day in the hot dry season (November), when temperature exceeded 32°C, flies concentrated in relatively cool dark places called refuges, such as the rot holes and shady bases of large trees. This refuge-seeking behaviour, and the critical temperature threshold, had been identified long before in laboratory work (Jack, 1939). Further work by Vale (Vale, 1971) investigated the field response to refuges more fully, using artificial mock-ups of them. He indicated that male and female of *G. m. morsitans* and *G. pallidipes*, in a range of nutritional states, occupied refuges between 0600 hours and 1800 hours during the hot dry season (Figure 1.1). He found also that refuge-seeking behaviour was confined mainly to the relatively shady areas, such as riverine woodlands.

As a consequence of these studies, the first ground spraying operations in Zimbabwe focused on the application of insecticide to riverine areas. Various types of natural refuges were

specified for treatment, but boles and larger branches were also sprayed, being places on which flies rest in cooler times of the day. The spraying was conducted in the cool dry season, to be in place by the onset of hotter weather in which the flies appeared to adopt the riverine situations as their homes.



**Figure 1.1:** Total number of tsetse recorded at each monitoring of a box refuge and a rot hole as a percentage of those observed at 1400 hours (left). The diurnal meteorological (right) (adopted from Vale, 1971)

ii) *Is riverine vegetation really an important home?*

One of the main spurs to reconsidering the importance of riverine vegetation was the experience that Pilson and Leggate had while making hand-net catches of fed flies from stationary oxen during the aforementioned studies of feeding and resting behaviour at Rekomitjie. They were impressed by the fact that the fed samples contained proportions of females that were very much greater than in flyround samples (Pilson and Leggate, 1962a). Given that the abundance of females is the prime factor determining the reproduction rate of tsetse, and hence population survival, the question arose as to whether the sampling system based on fed flies caught from oxen would indicate that riverine vegetation was as important for females as it seemed to be for males in the hot dry season.

In considering where to answer this question, it was inappropriate to work at Rekomitjie. This was because most tsetse control in Zimbabwe was then being performed against *G. morsitans* in the middle veldt, whereas most of the flies available at Rekomitjie were *G. pallidipes*. Moreover, the vegetation at Rekomitjie did not represent the full range of vegetation of the middle veldt. In order to address their concerns the Pilsons (Miss Leggate became Mrs Pilson) had to relocate their work from Rekomitjie to Lusulu, in the middle veldt of Sebungwe. Their results (Pilson and Pilson, 1967) suggested that at all times of the year, including the hot dry season, females were most abundant in the deciduous woodlands.

This unexpected result was backed up by the physiological studies of Bursell who found that flies sampled from stationary oxen and from fly rounds were larger and better fed in the deciduous woodland, rather than the riverine, at all seasons (Bursell, 1966). There was, therefore, nothing to suggest that the flies in the deciduous areas were in any sense 'lost' from their true home. Hence it seemed that the populations in the deciduous woodland were self-supporting, and could not be eradicated simply by spraying or removing the distant riverine vegetation. (Bursell, 1970) also refuted Jackson's implied notion of the directed movement of the flies between homes and feeding grounds. In particular, he indicated that random dispersal of tsetse, rather than deliberate to and fro movement between specific places, offered a better explanation for the mark and recapture data of Jackson.

All of this research by the Pilsons and Bursell undermined the confidence in selective bush clearing and policy of directing the ground spraying primarily to the riverine woodland. Thus, while the woodland along rivers was still sprayed, emphasis shifted to spraying on parallel transects, especially in the new international operations with South Africa and Mozambique (Robertson, 1968), that were begun in the SE of Zimbabwe in the late 1960s, where the vegetation comprised large homogeneous blocks of deciduous woodland.

### *iii) What insecticides to use*

The first insecticide used for ground spraying in Zimbabwe was dieldrin, commonly applied as a 3.1% emulsifiable concentrate (EC), but it was so expensive that the spraying could not be conducted on as large a scale as required. The extensive ground spraying in other parts of Africa, notably West Africa, e.g., Nigeria, used the much cheaper Dichlorodiphenyltrichloroethane (DDT) wettable powder (WP) (Barrett, 1997). Hence, tests were made of the relative efficacy of dieldrin and DDT, as WPs or ECs, at Rekomitjie (Vale,

1969). It was shown that 5% DDT WP was the most cost-effective of the option tested, being two thirds of the cost of the dieldrin formulations. This led to the wholesale adoption of 5% DDT as the insecticide of choice for ground spraying in Zimbabwe, so allowing greater areas to be treated annually. Costs per km<sup>2</sup> were eventually reduced further by lowering the concentration of DDT WP from 5% to 4%. That policy for the insecticide used remained in force until the cessation of ground spraying with DDT, on ecological grounds, in 1990. However, following the demonstration, at Rekomitjie, of the efficacy of deltamethrin on cattle and artificial host-like baits (discussed later), a small ground spraying operations was performed in the Doma area to show that this insecticide, which is relatively friendly to the environment, can be used as a substitute for DDT -- albeit that it doubled the operation cost per km<sup>2</sup> (Chadenga, 1992; Pilosof, 2016).

The notion that the use of DDT was a serious risk to the environment was perhaps overplayed by the wildlife lobby, as indicated retrospectively by the DFID-funded DDT Monitoring Project carried out between 1987 and 1992 (DFID, 1998). The project provided new scientific knowledge on the extent and nature of DDT's environmental impacts in the tropics. It noted that DDT would not probably be particularly damaging if it were not applied repeatedly in the same place. The problem was that in some places it had been applied repeatedly, as for example 2-3 times in NW Zimbabwe (TCD, 2020); to be discussed fully in Chapter 2) and if the technique continued in use, it was likely that such repeated applications would continue in many places.

#### *iv. Logistics*

Ground spraying technique requires huge capacity building for it to be operational. For example, it required the use of huge numbers of lorries, many landrovers for supervisory staff and a vast and seasonal labour force. Moreover there was the need for many knapsack sprayers, canvas tents to accommodate staff in the field, and communication radios to monitor progress. The upshot was that ground spraying fell out of favour -- not just because of its environmental risks, but also because of its logistical problems.

#### **1.1.1.5 Development of Aerial Spraying**

The efficacy of this technique had been demonstrated in the operations in Zululand early in the second quarter of the 20th century, which led to the permanent eradication of *G. pallidipes* (Du Toit, 1954). The success of this operation was based on some important

facilitating factors in the area. For example, the sprayed area in was isolated, especially because agricultural activities and hunting in the neighbouring areas minimised the risks of invasion (Hargrove, 2003). However, aerial spraying was not taken up immediately for large-scale use elsewhere because it had required up to 15 successive applications. There was a small exploratory operation near Makuti in 1955 (TTCB 1971 annual report), but the presence of large, tall trees in some places was considered to make flying hazardous. Moreover, the pilots, who were ex air-force personnel, were free-thinkers and difficult to manage, whereas the personnel employed on other control measures were part of the national civil service, and could be managed more tightly. Hence, the idea of using aerial spraying in Zimbabwe was put to rest during the 1960s.

However, aerial spraying was tried again in the early 1970s at Chiwonde, partly because there was worry about the logistical aspects and environmental risks of ground spraying (Chapman, 1976). The results, using sequential application of thiodan, were good, although there was the problem that aerial spraying with non-residual insecticide gave no protection against invasion. Associated with Chiwonde trials, studies were made of the impact on creatures other than tsetse. The results (Cockbill, 1968) suggested that there was no material effect on a range of creatures studied, except for fish in shallow ponds. Despite the encouraging indications of the Chiwonde trials, the development of aerial spraying was not continued in the few years thereafter, largely because of the war, which intensified between 1975 and 1979, making it difficult to conduct large scale research in remote areas.

It was only after the Zimbabwe liberation war from British colonial rule, when tsetse control was resumed in the early 1980s, that more could be done to refine the aerial spraying technique. This work was performed by the TTCB in co-operation with the Natural Resources Institute, initially under the International Pest Management Initiative (IPMI) of DFID and later with the Regional Tsetse and Trypanosomiasis Control Programme for Malawi, Mozambique, Zambia and Zimbabwe (RTTCP). The development programme was led largely by Reg Allsopp, as the main technical advisor. It involved switching from thiodan to a pyrethroid insecticide, deltamethrin, and much refinement to the spraying equipment and the system for guiding planes more reliably at night. However, there was no real, affordable solution to the problem of spraying in broken terrain. Although Allsopp did claim that the technique could be used in what he called "broken" or "rugged" terrain, especially if helicopters were employed (Allsopp, 1984), it was hardly feasible and affordable on the

Zambezi escarpments and other mountainous areas. There were also worries that the insecticide might not get to tsetse in the varied air currents associated with the very rugged places that occurred in much of the infested area in Zimbabwe.

It was encouraging, however, that the assessment of ecological risks by the Scientific Environmental Monitoring Group (SEMG) of the RTTCP was extremely comprehensive. Its findings were much more wide-ranging than those of the Chiwonde work of 1974 but they boiled down to essentially the same conclusion; there are no great risks of environmental damage in most places, except for shallow aquatic environments.

#### *Small-Scale Experiments*

Virtually all of the above investigations of spraying technology and environmental impact were performed as operational research during large-scale campaigns. Inevitably, therefore, the research was costly and protracted. However, small-scale experiments were performed at Rekomitjie (Vale *et al.*, 1984) to focus relatively quickly and cheaply on a comparison of insecticides and some of the limitations of aerial spraying. The technique involved releasing marked flies in the middle of a square block of woodland, about 2 x 2 km at dusk, and then spraying the whole area. The efficacy of the insecticides was scored partly by the numbers of marked flies that could be caught over the next few days, and also by the decline in catches of unmarked flies.

Results indicated no clear difference between the efficacy of thiodan at 14 g/ha and deltamethrin at 224-250 mg/ha, but they did suggest that the spraying did not produce perfect mortality among the released *G. pallidipes* -- about 3% of the population surviving a single application. Moreover, the rates of invasion of the sprayed area were exceedingly high, the mobility of female *G. pallidipes* being especially high at about 800 m/day. It was concluded that aerial spraying might be less effective against *G. pallidipes* than against *G. m. morsitans*, and this seemed to be confirmed by the operational experience considered in Chapter 2.

#### **1.1.1.6 Sterile Insect Technique**

##### *Releases of Sterile Males*

American scientists became interested in the use of the SIT for tsetse in the early 1960s, following the experience of the effectiveness to the technique against screw-worms in the USA. The first field trial of SIT against a wild population of *G. m. morsitans* in Zimbabwe

was conducted in the ~4.5 km<sup>2</sup> of Antelope Island, Lake Kariba (Dame and Schmidt, 1970) by an American-funded team under Dave Dame, with “Fido” Phelps as a local member of the team. The TTCB co-operated fully with the SIT researchers, and provided assistance whenever requested. Some of the activities carried out by members of the TTCB included the provision of extra personnel for game counts on the island. Two aerial spraying operations with lindane were used to suppress tsetse populations prior to release of sterile males, which were introduced as sterilised pupae.

The technique was highly successful in getting rid of the flies from the island, but the TTCB deemed it too complex and costly for routine use in Zimbabwe. In any case, the American scientists pulled out of Zimbabwe as soon as possible after the Unilateral Declaration of (Rhodesian) Independence in 1965. The American work on SIT was then established on Mkwaja Ranch, Tanzania (Williamson *et al.*, 1983), and was later taken up by the International Atomic Energy Agency and collaborating partners in various places in West Africa (Politzar and Cuisance, 1984) and Nigeria (Oladunmade *et al.*, 1990). All of this work was conducted on the African mainland where invasion of tsetse could occur, so suffering from the fact (Vale and Torr, 2005) that SIT is poorly effective against mainland tsetse populations since the method cannot stem invasion. The underlying reality is that sterile-mated flies can travel far and transmit trypanosomes for several months, but a dead fly can do neither. Sterilised flies are now, however, treated with samorin to kill trypanosome parasites, therefore, preventing transmission of the parasite from the fly to the host animal. However, a wild, sterile-mated female can still transmit. Subsequently, the problem of tsetse invasion was avoided by dealing with relatively small isolated populations, as on Unguja island in Zanzibar, Tanzania (Msangi *et al.*, 2000; Vreysen *et al.*, 2000) and in the Niayes, Senegal (Sall, 2015). Another problem occurring in all of the study areas was that SIT was very costly. Hence, it could be implemented only after the population has been drastically reduced by other techniques that involved the use of insecticide. .

To address the challenge of operational costs, collaborative research, between the IAEA and scientists in Zimbabwe, has been initiated to assess the feasibility of using drones to release sterile tsetse (TCD Reports, 2018). That technique still needs refinement since in the latest test (unpublished) the drone repeatedly lost its guiding signal due to the limited bandwidth in the mountainous Zambezi Valley. A signal mast will be erected at the centre of the 9km<sup>2</sup> study block to provide sufficient bandwidth to the drone.

### *Autosterilization*

Despite these problems with SIT, the Zimbabwe Government kept to the long established policy of exploring the potential for local refinement and adaption of all control measures. Thus the Government ran its own test of SIT against *G. m. morsitans* and *G. pallidipes* on Antelope Island (Vale *et al.*, 1986), but this involved automatic sterilization and release of field trapped flies, as discussed later under bait development. The technique was found to be effective in sterilizing flies but it was far too complex and costly to be considered for use in large, routine operations.

Another type of SIT was developed and tested against *G. m. morsitans* and *G. pallidipes* in a 12.3 km<sup>2</sup> block at Rekomitjie, primarily by Hargrove and Langley, with support from the Overseas Development Administration of the UK, and the encouragement and assistance from the Zimbabwe Government (Hargrove and Langley, 1993). The technique relied on attracting tsetse to odour-baited targets (discussed later) where the flies picked up a dose of pyriproxifen, a hormone analogue that mimics the natural juvenile hormone of insects (Sullivan and Goh, 2008). Pyriproxifen transfers from the treated mother to the larvae and hence to the pupae, so preventing the development of new adults. While the technique was demonstrated as effective, it threatened to work less rapidly than insecticide-treatment of targets. Moreover, chemical analysis of samples of target fabric after four months revealed that 68-85% of the hormone had dripped off (Hargrove and Langley, 1993). Hence the work with pyriproxifen-treated targets was discontinued, although it was considered useful to hold the technique in reserve, against the day that a resistance of tsetse to insecticide might occur.

#### **1.1.1.7 Refinement of Host Elimination**

In the 1950s and 1960s, anxiety over the efficacy, feasibility and cost of the various techniques considered as replacement for host elimination raised questions about what could be done to make elimination of hosts more selective and hence less objectionable. The prospects for this seemed enhanced by the use of antibody techniques to identify the bloodmeals of *G. m. morsitans*, *G. pallidipes* and *G. swynertoni* in East Africa by researchers such as Weitz and Jackson (1955) and Weitz and Glasglow (1956). Such work indicated that tsetse feed almost exclusively on just a few mammals, particularly suids and certain bovids such as bushbuck. Many other animals such as impala, hartebeest, Zebra or topi, contributed little to diet, despite often forming much of the wildlife population.

### *Nagupande Experiment*

The first test of selective elimination of host was conducted in Zimbabwe in 541 km<sup>2</sup> of infested territory on the headwaters of the Nagupande river in the Binga District. Some preliminary hunting occurred in the area from 1958 to 1960 (Lovemore, 1963). However, the main hunting occurred in the 24 months, starting in 1962, when hunters removed warthogs, bushpigs, bushbuck and kudu. After the first three months of hunting, the catches of *G. m. morsitans* in the area declined exponentially relative to those in a control area. These results are indicated most satisfactory by Hargrove (Hargrove, 2003). In consequence, the technique of selective hunting was adopted as the year-round backbone of control efforts for the next decade.

### *Further Attempts to Refine Host Elimination*

Following the success of the Nagupande experiment, it was required to determine the efficacy of being yet more selective in eliminating hosts. This required much more work on the identification of bloodmeals. In the early stages, bloodmeal samples had been sent overseas for the identifications, but in the late 1960s the TTCB established its own identification centre, with Edith Steinberg as the immunologist, working under the Veterinary Officers of the Branch, i.e., Bill Boyt and Peter Mackenzie. The over-riding indication was that *G. m. morsitans* obtained their blood meals from four mammals, with the main single host in most areas being the warthog, which contributed up to about 80% of the diet (Robertson, 1983). Hence, it was required to assess the extent to which the hunting of warthogs alone would affect tsetse populations.

Work to address this matter began in 1967 in a square bloc of 11 km<sup>2</sup>, in the Sengwa Wildlife Research Area which forms part of the Chirisa Game Reserve. The project was a cooperative venture between the TTCB and the Department of Parks and wildlife Management (Vale and Cumming, 1976). It showed that on getting rid of favoured hosts, the warthog, tsetse took 20-50% of blood meals from elephants and a large proportions of the remainder from bovids (Vale and Cumming, 1976). On chasing the elephants away, the flies fed on kudu. None of these changes in diet caused any material change in the apparent numbers and welfare of tsetse. Thus there seemed little scope for making host elimination more selective.

### **1.1.1.8 Development of bait science**

To complement the above studies of the effects of depriving tsetse of certain hosts, there were also studies of how tsetse responded to various hosts and artificial baits. This work was to have great importance in developing new methods of controlling and surveying tsetse populations.

#### *Early work at various places*

The sampling technique developed by Pilson and Leggate at Rekomitjie, comprising handnet catches of fed flies from stationary oxen, was a great improvement over the flyround in that it gave a more representative sample of the tsetse population (Pilson and Leggate, 1962a). However, the results of the study by the Pilsons at Lusulu in 1966 showed that even with this technique the female percentage in samples was rarely above 40 percent, i.e. much less than the 67% expected in genuinely representative samples of the wild population -- allowing that males and females emerge in equal numbers and females live twice as long as males (Pilson and Pilson, 1967). Moreover, studies by Phelps at Chirundu showed that the female percentage in the samples obtained by the ox technique much lower than 40% there (Phelps, 1968). Furthermore, the samples of tsetse from the artificial refuges operated at and near Rekomitjie in 1966 and 1967 (Vale, 1971) indicated, contrary to the findings of the Pilsons, that both males and females concentrate there, at least in the middle of the day in the hot dry season.

The upshot of all these considerations was that the sampling science for tsetse was far from satisfactory. The general problem was that various sampling systems offered widely different indications for population distribution, and also for population composition, in respect of the relative abundance of the sexes and species, age classes and physiological states. It was especially depressing that the traps which seemed to give representative proportions of females gave very few catches per day, whereas the systems giving good daily catches gave much lower proportions of females, sometimes hopelessly low proportions. Thus, it seemed that we really must be missing some extremely important thing in the responses of tsetse to baits. What benefits might rise from finding the missing information? The matter was addressed alongside the Sengwa work on host elimination.

### *Sengwa work on bait performance*

The most striking thing about the Sengwa data for bloodmeal identifications (see above) was the marked predominance of warthogs, which applied to the diet of both male and female tsetse throughout the area. Warthogs were known to occur at Sengwa at a density of about 10 per km<sup>2</sup> (Vale and Cumming, 1976), so that each individual pig was estimated to attract on average a sizeable proportion, at least 8%, of the adult tsetse population per 3-day hunger cycle. The implication was that a sampling system that simulated a warthog would be a very good device for getting large and representative samples of the tsetse population, and would be an excellent benchmark against which to judge other sampling devices. The catch data from field studies could then be interpreted more reliably, leading to a fuller and more confident understanding of the distribution, behaviour and population dynamics of field populations. Moreover, given that tsetse populations cannot withstand an enhanced adult death rate of more than about 3.5 % per day (Hargrove, 2004) deploying artificial, warthog-like baits at several per km<sup>2</sup> would provide an effective and ecologically clean method of tsetse control.

Work towards making artificial baits as effective as a warthog began by observing how tsetse behaved around tame warthogs and other animals (Vale, 1974a). At the same time, a model of a warthog was made from a steel drum, 70 cm in diameter and 50 cm long. It was thoroughly cleaned, painted non-shiny black and mounted horizontally 37cm off the ground on a set of pram wheels (Vale, 1974d). To try to ensure that the model represented a wild warthog, it was moved through the bush in the absence of men. This required a wide range of methods of capturing flies at baits, the most efficient and adaptable being a variety of electrocuting devices (Vale, 1974b). Experiments focussed largely on the way that tsetse responded to these models, to men and to the combination of a model with a man walking nearby, in simulation of a handnet catcher. The main findings of this early work at Sengwa were that models were highly attractive on their own, catching many males and females, and that humans were repellent, reducing the catches from the models by about 75% for females and 50 % for males. It was also found that mobile men attracted many females -- the fact that handnets caught so few females was that such flies did not remain near humans for long, and rarely alighted on the humans.

### *Later work at Rekomitjie and Makuti*

The above discoveries at Sengwa were not extended there because once the studies of host depletion had been completed it was more convenient to move the bait research operations back to Rekomitjie. Key scientists in this research at the time were Glyn Vale and John Hargrove under Einar Bursell as mentor. Of immediate interest was the work on various sorts of mobile (Plate 1.1) and stationary baits (Vale, 1974c) and on effect of human presence (Hargrove, 1976). Such work confirmed that catching from stationary oxen, i.e. the Pilson technique, gave misleading samples -- partly because handnets could not catch some of the attracted flies, and because the handnet operators were repellent.



**Plate 1.1:** Mobile tsetse surveys in Zimbabwe; Bait ox (left) and Manscreen fly round (right)

In the late 1970s, progress on bait technology was hindered by the intensification of the war. Hence, research operations moved to the safer venue at Makuti and work was restricted. Moreover, Hargrove, one of the main scientists at Rekomitjie, took study leave and moved to Los Angeles, USA. The work carried out at Rekomitjie and Makuti, during the latter years of the war and thereafter was subject of several reviews and was captured on a BBC Horizon documentary “The men who bottled a cow”

<http://bufvc.ac.uk/dvdfind/index.php/title/13894>).

After independence in 1980, the pace of progress was greatly enhanced by the return of Hargrove and an influx of many cooperating scientists from overseas. These included Chris Green from The Tsetse Research Laboratory (TRL) at Langford, David Hall from Natural Resource Institute (NRI) at Chatham, and John Brady, Steve Torr, Gabriella Gibson, Nigel Griffiths and others from British academia. Among the locally employed scientists were Stanley Flint, Clement Mangwiro, Odwell Muzari, Andrew Chamisa, William Shereni and

more recently, David Tsikire. Some of the overseas scientists were employed through aid packages associated with the International Pest Management Initiative (IPMI) of the UK and through the RTTCP, supported by the European Union.

Much of the cooperative work involved basic biological studies of the way tsetse were attracted to baits and what they did on arrival. Some of this work concentrated on the effects of visual stimuli (Green and Cosens, 1983; Torr, 1988; Vale, 1993 and Santer *et al.*, 2019). However, given that host odours had been shown to be particularly important (Vale, 1974c; Hargrove and Vale, 1978) there was also a great effort to identify the attractive components of host odour, so as to be able to dispense them near artificial baits. The work on identification of odours was performed mainly as a tripartite arrangement involving: i) identification of candidate attractants by chemical analysis of odours at the NRI, ii) laboratory studies to screen candidate attractants for their ability to affect tsetse behaviour, at the TRL, and iii) field studies of the efficacy of candidate attractants at Rekomitjie.

By the 1990s, the most cost-effective blend of odour attractants consisted of a ketone, either acetone at 5 mg/h or butanone at 0.5 mg/h, with a blend of 1-octen-3-ol at 0.05 mg/h, 4-methyl phenol at 0.05 mg/h and 3-*n*-propyl phenol at 0.005 mg/h (Torr *et al.*, 1997). Special dispensers were designed by (Torr, Hall and Smith, 1995) with the ketones being released from open bottles and the other chemicals being put as a mixture into sealed sachets of low density polyethylene. The chemicals diffused slowly through the sachet walls and evaporated at the outside surface. Carbon dioxide was also identified as a potent attractant and was used in small scale experiments at around 2 lit/min, but it was too costly and inconvenient to use on a large scale (Vale and Hall, 1985).

The above research to develop artificial baits (Plate 1.2) led to recommendations for the use of improved survey devices Vale, (1993) particularly the stationary, odour-baited traps (Hargrove and Langley, (1990) and the vehicle-mounted electric traps (VET) (Plate 1.3, Left).



**Plate 1.2:** Evolution of trap in Zimbabwe from top row; Morris trap (left), Beta trap (right). Bottom row; F-trap (left) and epsilon trap (right)

To compliment methods currently in use for tsetse surveys, a geo-referenced flyround was developed and successfully used in trials conducted in Tanzania and Zimbabwe. A geo-referenced flyround fitted with several cameras and a GPS is able to pinpoint the exact position in which a fly is caught (Plate 1.3:, Right). The precise location of tsetse catches can help to identify “hot spots” in an area, which will help planning of tsetse control operations. The cameras are essential in behavioural studies of tsetse alighting to the bait.



**Plate 1.3:** Vehicle Mounted Electric Trap (Left) Vehicle Mounted Sticky Trap (Right)

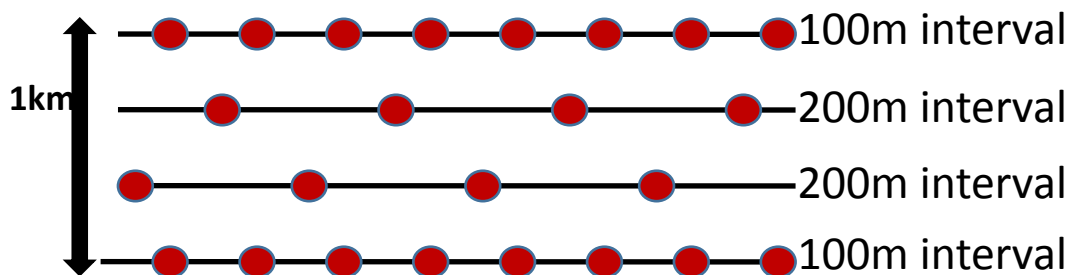
Research also led to artificial baits consisting of various forms of insecticide-treated targets to control the flies (Vale *et al.*, 1988). Initially the insecticide proposed for use on targets (Plate

1.4) was 3.1 % dieldrin EC (Vale *et al.*, 1986), but this was soon changed to ~ 0.1% by deltamethrin soluble concentrate (SC) which was considered to be more eco-friendly and shown to be suitably persistent on targets (Torr, Holloway and Vale, 1992).

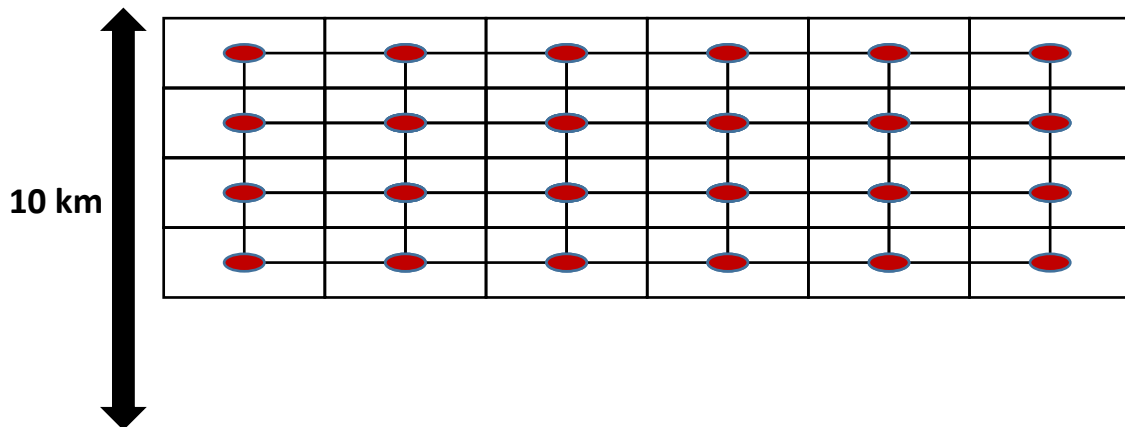


**Plate 1.4:** Target development in Zimbabwe; Rifa target (left) and S type (Right)

*Target Barrier Configurations*



**Figure 1.2:** Narrow target barrier



**Figure 1.3:** Wide target barrier with targets at 500m intervals

One advantage of the target technology is that it can be used to create barriers to tsetse invasions. Empirical mark-release-recapture studies in Matusadona National Park, NW Zimbabwe, FAO (1990), demonstrated that *G. m. morsitans* and *G. pallidipes* were unable to cross a 5km wide barrier with targets evenly distributed at 500m intervals. One km wide narrow barriers (Figure 1.2) allowed 10% of the marked flies to cross. However, Hargrove, suggested, through statistical modelling, that 8km wide barriers are 100% effective against both tsetse species (Hargrove, 1993). This resulted in the adoption of 10km wide barriers to prevent tsetse reinvasion (Figure 1.3).

### **1.1.1.9 Development of Insecticide-Treated Cattle**

#### *Early Work*

The use of cattle treated externally with DDT for the control of *G. pallidipes* and *G. swynnertoni* was investigated in East Africa in the 1940s (Vanderplank, 1947) and (Whiteside, 1949), but the results were not sufficiently encouraging to recommend the technique. DDT did not persist on cattle for long and was rubbed off when the animals walked through tall grass. In retrospect, however, the main problem was probably the failure to appreciate how rapidly the flies could invade, so that the areas of 6-13 km<sup>2</sup> chosen for the field trials were too small to show an impressive degree of tsetse control. Nevertheless, the idea of using treated cattle was revived in Zimbabwe in the mid-1960s, and focussed on small-scale bio-assays, at Rekomitjie, to assess how well various insecticides can persist in effective form after application (TTCB Annual Reports, 1967; 1968; 1968). By the end of that decade, a wide range of insecticides had been tested, including organochlorines and organophosphates, but none seemed particularly persistent. There was also the anxiety that the organochlorines, which tended to persist the best, would contaminate the meat or milk from the cattle. Moreover, in the late 1960s there was a concern, as discussed above, that the samples taken by handnets from cattle were poorly representative of the wild tsetse population. Hence, could the killing of tsetse attracted to cattle be basically capable of achieving a suitable degree of population control?

#### *Later developments*

During the 1970s, the improved understanding of bait- orientated behaviour had shown how very attractive cattle were when humans were not near them, and how much catches could be enhanced when and flies visiting the baits were caught efficiently (Vale, 1974c; Hargrove, 1976). This prompted a reconsideration of the use of insecticide-treated cattle. The prompting

was increased yet further by the mid-1980s when it had been shown that deltamethrin SC was highly effective on targets. It was particularly significant that this insecticide had already been approved by the Zimbabwean regulators for use on cattle as a means of tick control and could therefore be applied to cattle for controlling tsetse.

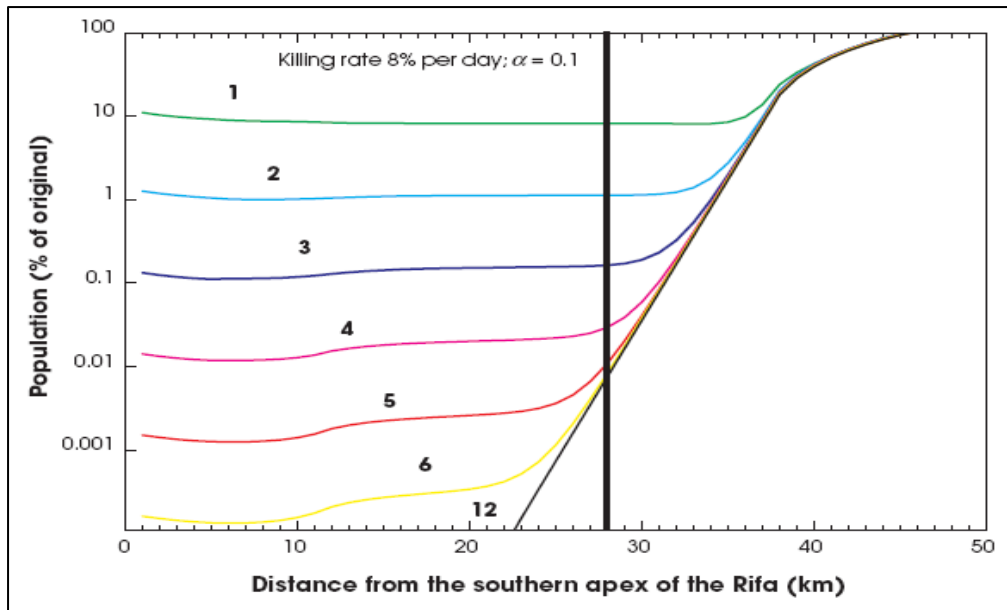
Research to investigate the efficacy of this method of tsetse control was then promoted largely by Alec Wilson, a retired Director of Veterinary Services who worked for Cooper Zimbabwe Ltd. He enlisted Madeleine Thompson, an MSc student, to investigate the matter by small-scale experiments at Rekomitjie, which indicated that the insecticide was highly promising (Thompson, 1987). Subsequently, deltamethrin-treated cattle were employed successfully in a small field trial covering 30 km<sup>2</sup> at Kotwa in the NE of Zimbabwe and then on a much greater scale in most parts of the Zimbabwe fly-belt, as discussed in Chapter 2. At the same time there was further work at Rekomitjie to demonstrate that a range of pyrethroids could be used as an alternative to deltamethrin (Mangwiro *et al.*, 1999; Vale, Mutika and Lovemore, 1999). It was also shown that the insecticide was effective if applied only to those parts of cattle on which tsetse feed, notably the legs and belly (Torr, Maudlin and Vale, 2007). This meant that the insecticide costs could be reduced by ~50-90%, and that the contamination of dung was thereby reduced greatly, so ensuring that the co-lateral damage to dung fauna was negligible (Vale *et al.*, 2015).

### **1.1.2 Background to development of tsetse models**

While all of the various sorts of technical developments were going on, much work in Zimbabwe was being performed by Bursell, Phelps, Hargrove and others to elucidate the physiology and population dynamics of tsetse with a view to explaining past successes and failures in tsetse control, and to help predict the degree of success of future options.

#### **1.1.2.1 Modelling of tsetse population dynamics**

For such purposes, all of the technical data and the information for population dynamics were fed into computer-based models of tsetse abundance, mobility and distribution, some of the pioneer tsetse models were developed by Hargrove to predict the rates of tsetse invasion and to explain the efficacy of targets in controlling the flies in the Rifa Triangle (Figure 1.4). Other models, e.g., Tsetse Muse ([www.tsetse.org](http://www.tsetse.org)), by Vale and Torr, introduced user friendliness into assessments of the costs and efficacy of control options.



**Figure 1.4:** Predicted population levels in the Rifa Triangle as a function of the mortality imposed due to targets and as a function of the diffusion coefficient ( $\alpha$ ). Each trajectory shows the predicted population along a line. The vertical line in the body of the graph indicates the edge between the Rifa and the main invasion area. Numbers in the body of the graph indicate months after the start of the control operation. A constant 8% daily mortality was assumed in the escarpment. Source (Hargrove 2003)

## 1.2 Discussion

### 1.2.1 Timelines in development

The main development of new control measures after the cessation of non-selective shooting of wild hosts in the late 1950s involved three phases, each about two decades long. The first phase, starting about 1960, was conducted mainly by local scientists and was characterised by gradually intensifying efforts to increase the variety of control techniques available. This was followed, around 1980, by a phase of intense research, particularly on aerial spraying and bait technology, aimed at refining the control measures that looked the most promising. This phase involved much international cooperation and support. Both of these had an impact on the practice and policy of tsetse control in Zimbabwe and elsewhere. However, from 2000, there was a gradual reduction in support from the international partners in development, as well as a decline in funding from government. This has reduced drastically the research output. However, prior to the restricted staffing associated with the Covid-19 epidemic, field research had continued at Rekomitjie in collaboration with international partners such as the WHO/TDR, the IAEA, the Liverpool School of Tropical Medicine, the Kenya Agricultural

& Livestock Research Organisation and university departments in Zimbabwe, Greenwich, Bristol and Stellenbosch. It is expected that field collaboration with these organisations will be re-established once the Covid-19 pandemic is over. Moreover, the station has retained its title as The Centre of Excellence for tsetse research within the SADC region. Research, in recent times, is focused on the impacts of climate change on the dynamic changes in tsetse populations in the Zambezi valley floor, geospatial science to understand key drivers in the dynamic changes in the distribution of tsetse and trypanosomiasis and, modelling to predict impacts of different control interventions and interpret changes in tsetse distribution patterns.

### **1.2.2 Evidence of Success/Impact of research and development in Zimbabwe**

The research on new methods of tsetse control in Zimbabwe has had a profound impact on control policies throughout Africa, as for example, the use of insecticide-treated cattle against various species of tsetse, the development and use of odour baited targets for savannah tsetse and the application of tiny targets against riverine tsetse. Targets are a simple and environmentally clean method of controlling tsetse. The quality and usefulness of this research was recognised by the many local and international honours and awards given to the research. The detailed list of the accolades from research carried out at Rekomitjie are shown after the conclusion section. The tsetse research to produce artificial host-like baits was listed in the top ten research projects in which scientists from the UK have been involved. Moreover, the Zimbabwe work has featured in two BBC Horizon programmes (28 July 1978; Episode 21) and the popular press, as for example, National Geographic (4 April 2014) and the Air Zimbabwe in-flight magazine (Sky Host, Vol. 4 No. 2). There are about 400 papers published on tsetse research conducted at Rekomitjie since 1959 -- a tribute to the productivity of the station.

### **1.2.3 Roots of Success**

To attempt to identify why the tsetse research in Zimbabwe has been so successful opinions on the matter were sought from the three researchers who, between them, were responsible for most of the work at Rekomitjie, namely, John Hargrove, Steve Torr and Glyn Vale. Although they were questioned separately, each indicated the following three factors as main roots of success. Firstly, in the early decades, senior officers of the TTCB had no overriding, preconceived ideas about research direction. There were certainly some general matters that research was required to address, particularly the development of cost-effective and environmentally friendly techniques for controlling and surveying tsetse. However, in

significant part the scientists were free to decide for themselves what types of technique offered the greatest promise, and how best that promise might be realised. Second, the Zimbabwe scientists were entirely open and eager to co-operate to the full with scientists from other organisations and countries, with no petty jealousies. These two factors are often not so clearly evident in other research organisations, but taken together at Rekomitjie they led to the third factor: success breeds success. So it was that tsetse research in Zimbabwe was able to attract more funds and establish highly beneficial links with eager and able scientists on a wide front. There are important lessons in all of this.

### **Honours and awards from research investigations conducted at Rekomitjie**

Tsetse research at Rekomitjie has generated knowledge on behaviour, ecology and physiology, and revolutionised the way in which tsetse control operations are carried out in Africa. Scientific publications from investigations at Rekomitjie are in excess of 400 based mainly on the aforementioned subjects. Collaborative research between Zimbabwe, academic institutions and several research organisations in the United Kingdom has produced several doctoral, Magisterial, Masters, BSc degrees and several accolades (Annexure 1&2).

### **Recommendations**

1. There is need to intensify research to develop new tsetse sampling and control techniques, refine existing techniques and, to identify new and more effective odour attractants and repellents.
2. Research should be pursued on the effects of climate change and habitat modification on the dynamics of tsetse and trypanosomiasis.

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## **Chapter 2 : History of Tsetse Control in Zimbabwe**

## 2.1 Introduction

This chapter discusses history of the control of *G. m. morsitans* and *G. pallidipes*, in Zimbabwe, and provides insight into the lessons learnt and guidelines on international best practice derived from case studies between 1980 and 2019. Following the loss of vast areas to tsetse reinvasion in the 1970s, the country made a concerted effort to rapidly reclaim all the lost ground and continue to progressively eradicate the fly towards international borders with Zambia and Mozambique. Efforts to eliminate trypanosomiasis from the country received a boost from the EU-funded Regional Tsetse and Trypanosomiasis Control Programme (RTTCP), which commenced in 1986 and ended in 2000. During this project, tsetse were cleared from 20 000km<sup>2</sup>, of mainly farming land, in Northern and NE Zimbabwe (Lovemore, 1999). A total of 50 000km<sup>2</sup> was reclaimed since 1980, reducing the infested area from 80 000km<sup>2</sup> to the current 30 000km<sup>2</sup> i.e. from 20% to 7.5% in the N and W of Zimbabwe. Generally, the terrain is less undulating above the Zambezi escarpment, in the farming area, and more broken and rugged below the escarpment. Operations were scaled down since 2000, as funding was mainly from government with minimal external support. However, unlike in the past when massive reinvasion occurred, cleared areas were successfully protected against tsetse invasions through the use of barriers of targets complemented by cattle dipping.

### 2.1.1 Early History

In the 19<sup>th</sup> century, before tsetse control began, tsetse infested more than half (200 000km<sup>2</sup>) of the country. This ecologically suitable area for tsetse was below the 1067m contour (Lovemore, 1999) with the high and sections of the middleveldt unsuitable for tsetse habitation. Area infested by tsetse was therefore divided into the northern and southern belts. The rinderpest epizootic of 1896, killed millions cloven-hoofed animals and caused huge famine and economic losses to African pastoralists and agriculturalists (Hokanson, 2019). High mortalities of cattle and game animals including buffalo, kudu, eland, bushbuck, warthog and bushpig were recorded. Associated with this, the distribution and abundance of tsetse were drastically reduced, so that flies in Zimbabwe occurred only in a few small foci in the northern half of the country. Considerable recession of tsetse was observed before the disease i.e. tsetse-transmitted trypanosomiasis was eliminated. After the rinderpest had been eradicated from Southern Africa in 1905, the livestock industry boomed, allowing populations of cattle and other domestic animals to increase in numbers and extend into areas deemed free from the constraints of tsetse (Gargallo, 2009). Recovery of natural host animals

led to the recovery of tsetse populations in both the northern and southern belts in the 1950s. In the south east, recovery of the fly population was exacerbated by reinvasion from neighboring Mozambique. It is estimated that the infested area roughly doubled, from 14 000 km<sup>2</sup>, between 1918 and 1928 (Chorley, 1933).

Thus, tsetse were perceived by government as a serious threat to the livestock industry, and so control began. The first tsetse operation in the country and Africa commenced in 1919, based on elimination of game. This strategy was based on the realisation that if you remove game animals, tsetse vanished and when animals recovered tsetse came back (Jack, 1914). Tsetse were cleared from 26 000 km<sup>2</sup> using game elimination by 1940. However, as detailed in Chapter 1, in spite of this success, government forbade the use of this technique following severe public criticism over negative effects of game elimination to the environment. Bush clearing, which had been used in East Africa, was considered more suitable because it was selective and discriminative and environmentally friendly (Ford, 1970). However, this technique was not suited to the long front of potential invasion in northern Zimbabwe and was used along the Mozambique border in the Chipinge area, in 1932, to prevent tsetse invasion from Mozambique. Unfortunately, this period coincided with the Second World War which disrupted effective implementation of tsetse control programmes resulting in tsetse reinvading cleared areas. After that war, game elimination was reintroduced to claim the area invading in Hurungwe district and new operations of Mkota, Ngarwe, Mutoko, Mudzi and Chikwizo area were initiated. Game and cattle fences, separated by an average of 15km wide animal-free zone, were constructed in all these operations.

The Sequential Aerosol Technique (SAT), commonly known as aerial spraying, was developed in Zimbabwe in 1950 and was introduced in Hurungwe in 1953. A small- engined aircraft was used and the insecticide was 4% w/v solution of Benzene Hexachloride (BHC) in dieseline. The results were unsatisfactory. A similar operation was conducted in Kariba in 1956 and in the Lubu Valley, Binga district in 1957. These were more successful than the preceding ones. Full details will be presented later. *G. pallidipes* was starting to reinfest the northern belt in the early 1950's. This species was first discovered in 1942, in small numbers, in Binga district and by 1952 had infested Kariba district. Initially, this species was considered less important, but had surpassed the *G. m. morsitans* population by the 1970's. It is believed that the *G. pallidipes* were invading from Mozambique because of its ability to disperse over long distances (Vale, 1974). Restricted game elimination was instituted to stop

tsetse, of both species, from invading from Mozambique in the vicinity of the Save and Runde rivers. Aerial spraying was again tried following improvement in the efficiency of the equipment used in this technique. The adjustment made it possible to spray in the night as opposed to earlier early mornings and late afternoon sprays. Two successful night aerial spraying were carried out in 1974 and 1975 in the Chirisa Safari Area of Gokwe (Chapman, 1976). Operations were scaled down in 1975 due to the security situation till the country attained its independence in 1980. Consequently, the northern belt expanded and a considerable ground reclaimed from the 1964 to 1975 was lost. The tsetse situation in southern belt did not show any significant change. In the NE of the country, where tsetse had advanced to as far as the Umfurudzi Safari Area, tsetse had reinvaded the country almost to the natural fly limit.

In 1960, a ground spraying operation was considered for the first time and a trial was conducted over 280 km<sup>2</sup> in the Maseme region of Binga after the Royal Commission had stopped game elimination. Motorized knapsack sprayers applied a 3.7% dieldrin emulsion during the late dry season on tsetse resting and refuge site. Tsetse were drastically reduced in the small scale field trial that was situated in the middle of a heavily tsetse infested area. Following this success trial, game elimination was terminated at the end of 1960. The northern belt expanded rapidly, particularly from the west of Sanyati River, following the cessation of game elimination as capacity to implement large scale ground-spraying operations was not in place. Bovine trypanosomiasis cases began to increase and spread to Hwange, Gokwe, Karoi, and Guruve areas. In the southern belt, tsetse had reinvaded Mwenezi and Limpopo drainages.

In 1962 and 1963, a compromise was reached to reinstitute game elimination due to the severe increase in the prevalence of trypanosomiasis in the country. This was after tsetse research at Nagupande (NW Zimbabwe) had identified preferred blood meals. During this operation, selective hunting of tsetse favoured hosts as warthog, bush pigs, kudu and bushbucks was adopted as opposed to the blanket shooting of all the animals. This operation eliminated 98% of tsetse. In 1964 the government employed an integrated approach involving selective hunting and strategic application of ground spraying. The government was made uneasy with ground spraying due to its ecological impacts and switched from dieldrin to DDT in 1968. In 1975, it was apparent that with the use of both selective hunting and ground spraying, eradication of tsetse in previously reinvaded area was achieved except in the NE

where operations were limited due to the war. Ground spraying, with DDT, remained the mainstay of tsetse control till 1980. The use of DDT was gradually de-emphasized and eventually abandoned in 1990, when it was replaced by the pyrethroid, deltamethrin.

### **2.1.2 Post-1980 History**

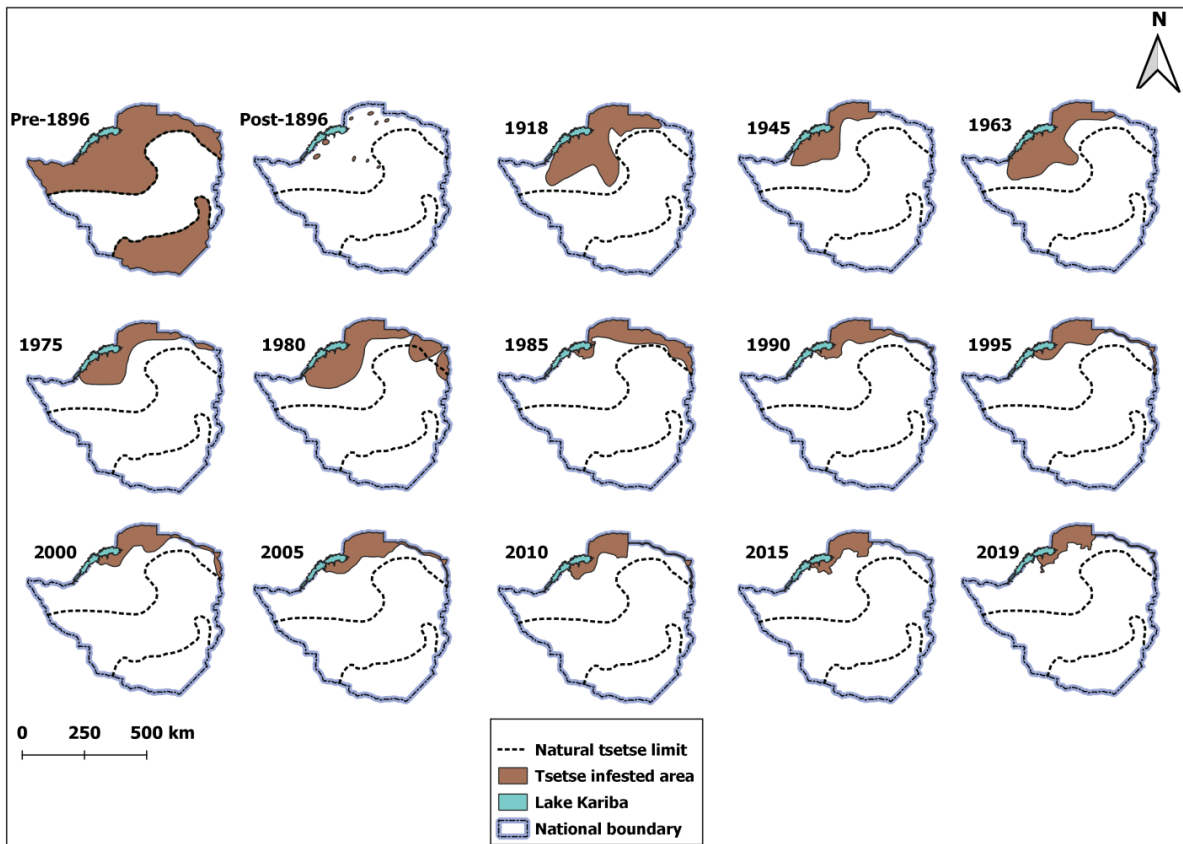
Post-independence strategy for tsetse control was to reclaim progressively areas lost during the war. Ground and aerial spraying, and insecticide-treated targets were used to control tsetse and rapid progress was achieved. Integrated use of these techniques in Sebungwe and Gokwe areas, in the first decade of independence, witnessed very rapid progress in reclaiming the ground lost during the war. In the north, in Hurungwe district, extensive tsetse control operations using ground spraying and insecticide-treated targets were employed.

In the SE, operations were limited mainly to monitoring of the Mozambique border to provide early warning of a reinvasion. In 1981, there was a limited incursion close to the Honde river, north the Save river. A ground spraying operation was implemented to eradicate the remnant flies and no resurgence of the tsetse problem was recorded.

The (RTTCP), 1986-2000, supported tsetse control campaigns in North and NE Zimbabwe. In the NE, this programme made considerable progress in pushing tsetse back to the Mozambique border. RTTCP programmes in Doma and Hurungwe, drastically reducing tsetse densities and so limited the invasion pressure on the settled area to the south. Aerial spraying was the main method used during the RTTCP and three operations were carried out in 1986, 1987 and 1988. Methodologies adopted using different control techniques highlighted in this section were described in finer detail in the RTTCP final report (Lovemore, 1999). The Government of Zimbabwe funded the ground spraying operation to protect the area to be aerial sprayed in 1986.

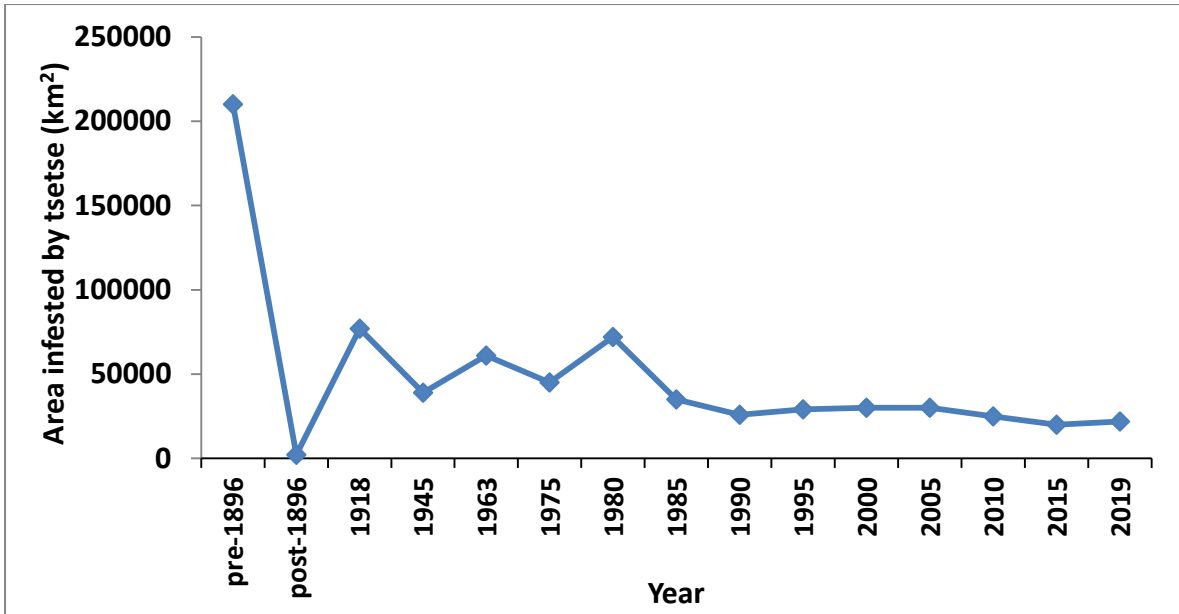
## 2.2 Trends in Tsetse and Trypanosomiasis distribution and control interventions

### 2.2.1 Changes in tsetse distribution patterns in Zimbabwe: 1896 to 2019



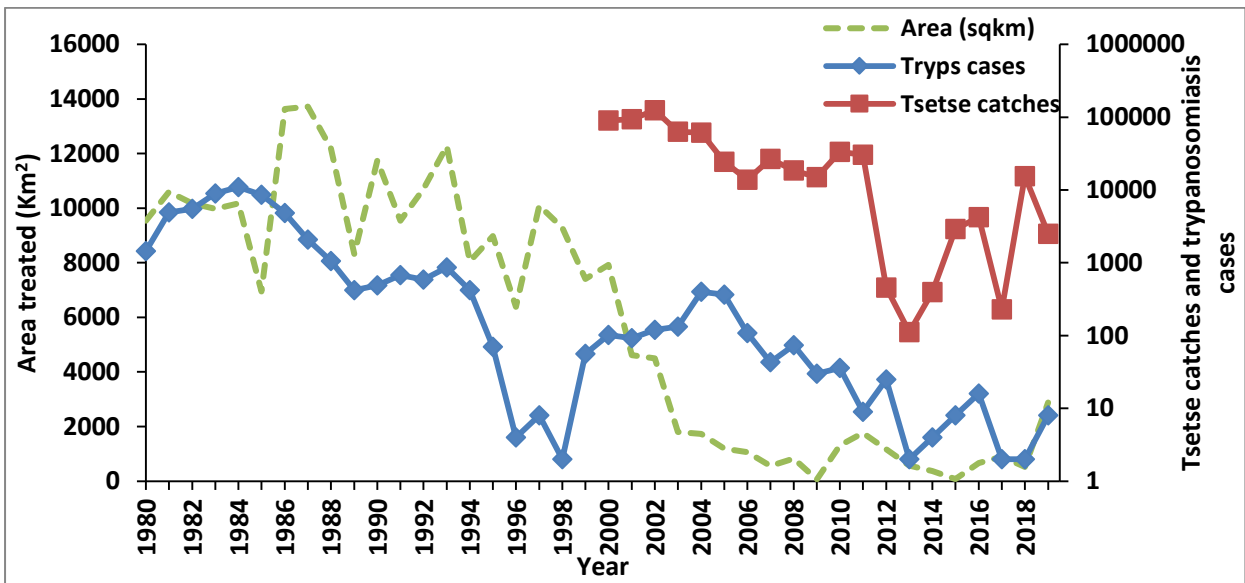
**Map 2.1:** Changes in tsetse distribution patterns: 1896-2019

Map 2.1 shows changes that have occurred in the distribution of tsetse since the pre-rinderpest era, before 1896, to present day. Changes in the distribution patterns were influenced by dynamics changes in the key factors responsible for tsetse survival as will be discussed later in this chapter.



**Figure 2.1:** Progressive reduction in the tsetse infested areas in Zimbabwe: 1896-2019

Impacts of initiatives to eradicate tsetse in Zimbabwe are clearly demonstrated by the progressive reduction in tsetse infested areas (Figure 2.1) and a decline in the overall tsetse catch levels and the occurrence of trypanosomiasis (Figure 2.2).



**Figure 2.2:** Impacts of control on tsetse catches (2000-2019) and trypanosomiasis cases (1980-2019)

**Table 2.1:** Summary of regression analysis of tsetse and trypanosomiasis from 1980 to 2019

Period	Variable	Std error	t stat	P-Value	R <sup>2</sup>	Adjusted R <sup>2</sup>	Correlation coefficient
2000-2009	Tsetse	19.36	-0.43	6.70x10 <sup>-1</sup>	3.41x10 <sup>-5</sup>	-0.0002	-0.05
2010-2019	Tsetse	35.78	8.63	6.71x10 <sup>-18</sup>	0.0046	0.0046	-0.98
1980-2019	Trypanosomiasis	9.22	-4.09	1.46x10 <sup>-5</sup>	0.48	0.45	-0.63
2000-2019	Tsetse and Trypanosomiasis	3.14	-2.41	8.15x10 <sup>-6</sup>	0.75	0.72	+0.41

Source of data: Zimbabwe national atlas for tsetse and trypanosomiasis

Tsetse population declined significantly ( $P < 0.05$ ) from 2010-2019 compared to the period 2000-2009 ( $P > 0.05$ ) (Table 2.1). Bovine trypanosomiasis prevalence declined significantly over the four decades of the study period. Regression was used to analyse relationships between years and (i) tsetse and (ii) trypanosomiasis. Multiple linear regression was used to explore connections between time, and tsetse and trypanosomiasis, and their interaction. Correlation was strongest on the tsetse variable. An increase in tsetse densities was directly proportional with an increase in trypanosomiasis prevalence implying a positive correlation between the two variables.

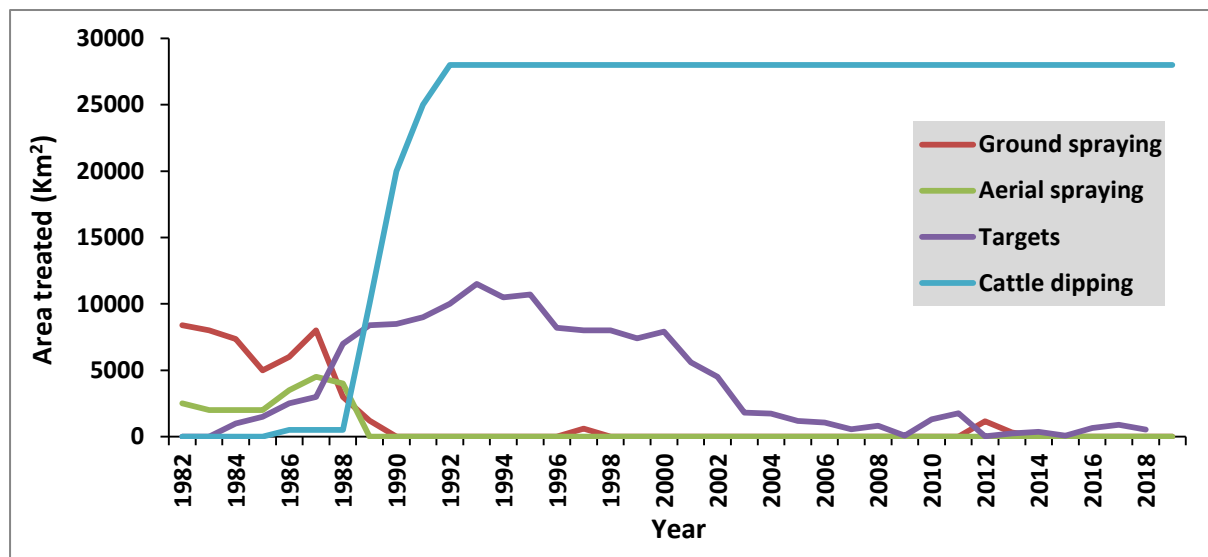
Massive tsetse infestation and trypanosomiasis cases recorded in the early 1980s were attributed to reinvasion which had occurred during the war years. As a result, aerial and ground spraying operations were launched to address the situation. Aerial spraying was chosen for its efficiency in clearing the fly in a short space of time and ground spraying to protect areas from further reinvasion. The operations proved successful as demonstrated by the reduction in trypanosomiasis cases.

Figure 2.2, shows an increase in trypanosomiasis cases from 1980 to 1984 due to the intensification of sampling effort after independence. Highest trypanosomiasis cases were recorded in 1984 and started to decline with increase in control activity till late 80s and early 90s, then leveled off from 1990 to 1993, before starting to decline to 4 cases in 1996. The

reduction in the intensity of tsetse control programmes in 2000, when the RTTCP project was terminated, resulted in the gradual increase in bovine trypanosome infection cases which later declined to constant levels due to the use of targets. Tsetse reinvasion occurred in Omay Communal land, NW Zimbabwe and an area of 1 500km<sup>2</sup> was lost.

### 2.2.2 Techniques applied in integrated control programmes in Zimbabwe

The most widely used technique in the country is cattle dipping (ITC) followed by insecticide treated targets (ITT). Ground spraying was mainly the technique of choice from 1980-1990 although it was later used in 1997 and in 2012 (Figure 2.3).

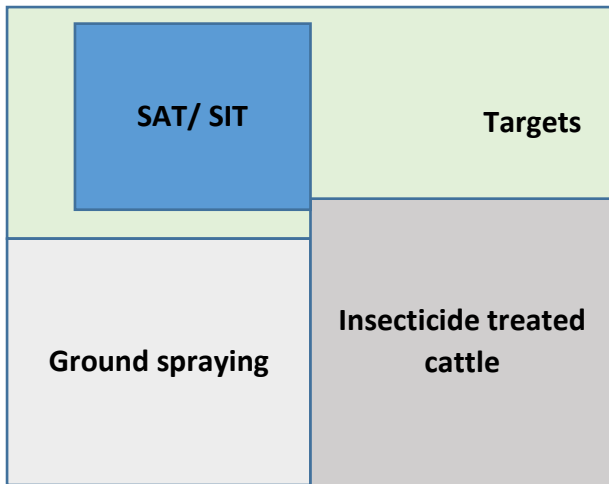


**Figure 2.3:** Changes in areas treated using different control techniques

### 2.2.3 Different forms of integration of control techniques

#### 2.2.3.1 Mosaic of techniques

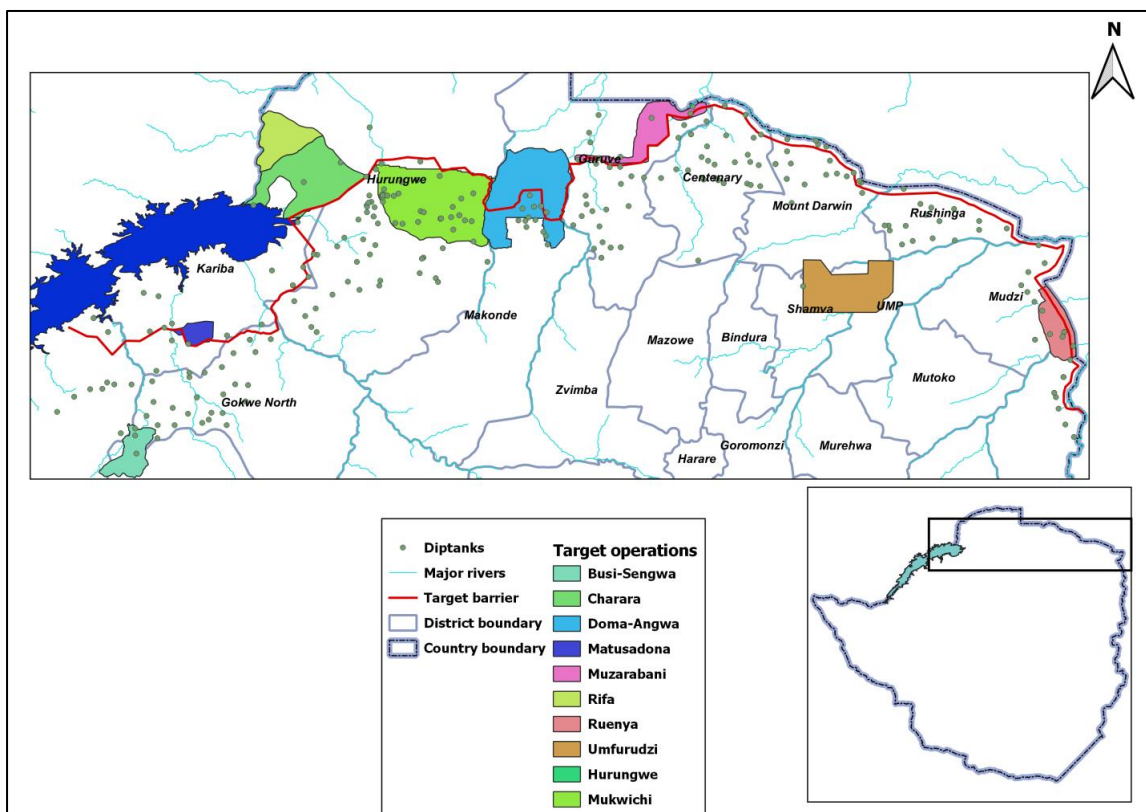
This refers to a scenario where different techniques are used side by side in adjacent areas, in the same year. Often this is dictated by the need to isolate and protect areas that are to be treated with non-residual pesticides as in the case of aerial spraying. Two or more techniques may be used in a mosaic including say, ground spraying, aerial spraying, targets and cattle dipping (Figure 2.4). A typical example of a mosaic was the integrated operation in 1986 in Umfurudzi, NE Zimbabwe during the RTTCP.



**Figure 2.4:** A “mosaic” of different control measures

***Mosaic of barriers of insecticide treated targets and insecticide treated cattle***

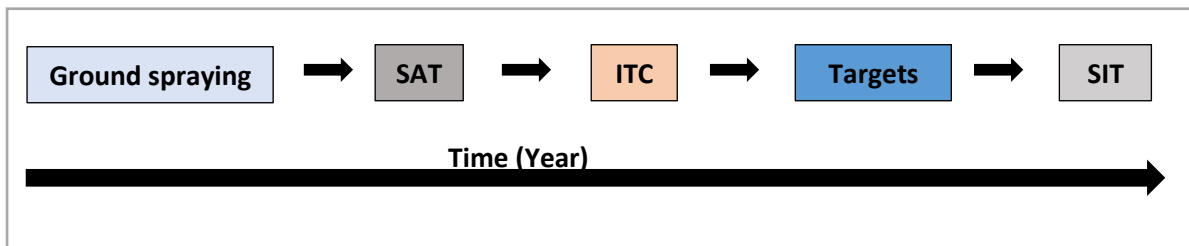
It is recommended to use control measures which will impact on the tsetse population in a similar manner to avoid the problem of reinvasion from one block to the other. Map 2.2 illustrates how diptanks (ITC) were used to complement targets (ITT).



**Map 2.2:** Integrated operations using ITC and ITT (Targets): 1984-1990

### 2.2.3.2 Series of different techniques

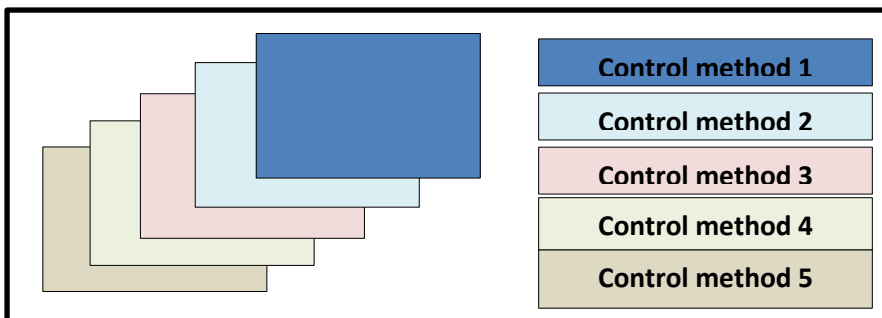
Different techniques are applied over consecutive years in AW-IPM programmes. A single technique is used at any given time (Figure 2.5)



**Figure 2.5:** Application of different techniques in a progressive manner over time

### 2.2.3.3 Layers of Control techniques

Refers to a situation where different techniques are applied against the same population at the same time (Figure 2.6). This is not usually applied in tsetse control and is more applicable in mosquito control.

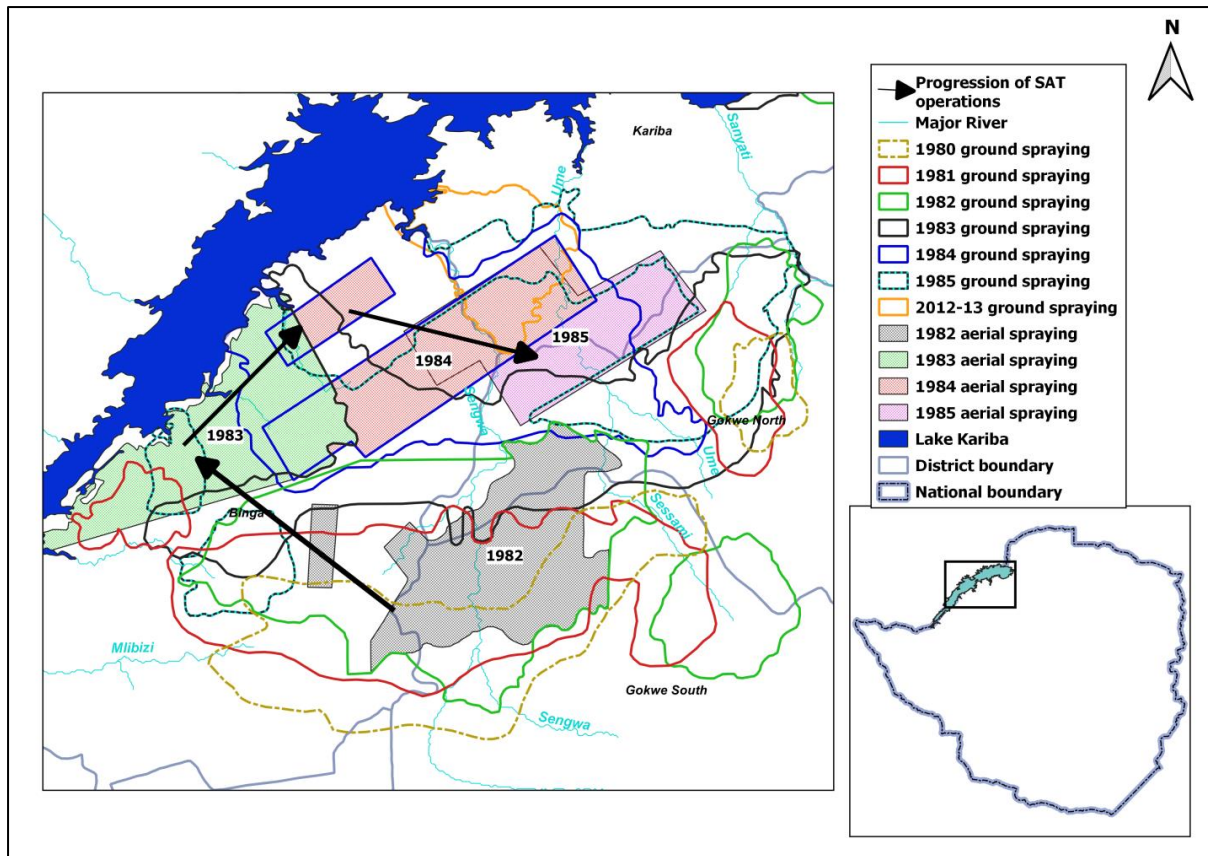


**Figure 2.6:** Various techniques implemented simultaneously

## 2.2.4 Strategic and Tactical approaches in tsetse control in Zimbabwe

### 2.2.4.1 Progression of tsetse control programmes in NW Zimbabwe

Tsetse control operations in NW Zimbabwe were resumed in 1980 using ground spraying, sequential aerial spraying (SAT) using the mosaic approach (Map 2.3) and limited selective game elimination. Ground spraying and selective hunting were used in 1980 while ground and aerial spraying were the techniques of choice from 1982 to 1985. Following the development of insecticide treated targets in 1985, operations in NW Zimbabwe were based on the integration of targets and ground spraying from 1986 to 1990. After ground spraying with DDT was phased out in 1990, targets became the mainstay of control, occasionally supported by ground spraying with deltamethrin applied as a residual deposit. Tsetse control operations were implemented, in a progressive manner to eradicate tsetse from NW Zimbabwe.



**Map 2.3:** Aerial and Ground Spraying Operations in NW Zimbabwe: 1980-1985

#### 2.2.4.2 Ground Spraying operations: 1980 and 1981

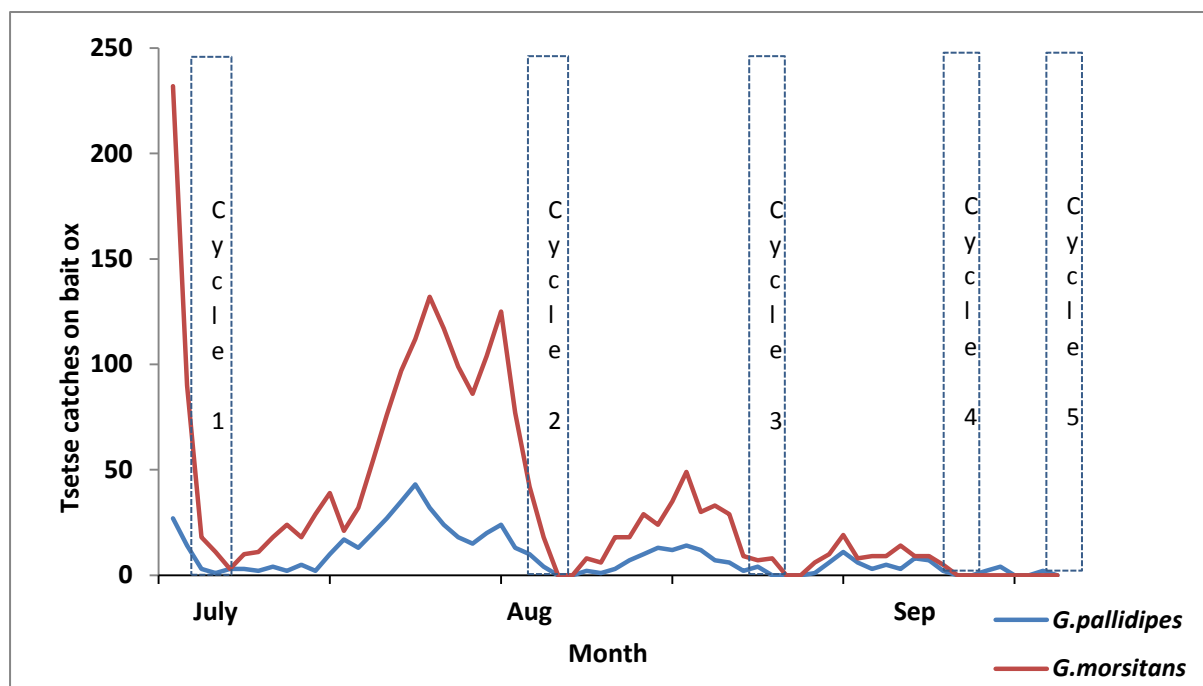
Ground spraying was the method of choice immediately after independence in 1980. Operations were conducted in and around Chirisa game reserve using 5% DDT wettable powder suspension covering 1 997km<sup>2</sup>, west of Sengwa river. An additional 125km<sup>2</sup> was treated, east of the Sengwa, with 2.5% DDT suspension. The 2.5% DDT was used on a trial basis to validate the experience in Nigeria where it was successfully used. However, survivors were captured after the operation. The decision to use a reduced concentration was to cut on the cost of ground spraying and minimise environmental damage.

#### 2.2.4.3 Ground and Aerial spraying operations: 1982-1985

In 1982, there were overwhelming trypanosomiasis cases in Chirisa area despite there being very few tsetse flies comprising mainly *G. m.morsitans* at a low density. A strategy that would quickly get rid of the flies, aerial spraying was adopted. This was so mainly because there were serious concerns about tsetse getting into the Hwange National Park. The operation was a huge success and the technique worked as per expectations. An integrated operation involving the use of ultra-low volume, non-residual aerial spraying and DDT

ground spraying was put into operation for the first time. Aerial spraying was done using endosulphan and total eradication was achieved. In addition to aerial spraying operations, selected species game elimination was continued south of the game fence.

In 1983, the same approach of integrating SAT and ground spraying and some limited selective game elimination, was again adopted in a block where there were more flies and exposed to a greater tsetse invasion pressure. An area of 2 100km<sup>2</sup> was demarcated for aerial spraying in order that it may be tested and its potential assessed for use in even more rugged terrain which comprised hills and deep valleys.



**Figure 2.7:** Changes in pre and post aerial spraying tsetse catches from bait oxen (NW Zimbabwe, 1983) (Source: Hursey and Allsopp, 1984)

Terrain in the 1983 SAT block was rugged along the Ruziruhuru river with a few patches of flat terrain near the Sijarira forest. Deltamethrin applied at 0.25g a.i/ha replaced endosulfan in the first cycle of this SAT operation. Survivors were recorded after this operation but were eradicated after switching to endosulphan in the last 4 cycles (Figure 2.7). Performance of this aerial spraying was satisfactory although it did not work quite as good as in 1982 due to greater reinvasion and more rugged terrain.

The objective in the 1984 aerial spraying operation was to continue pushing the fly front back in a north-easterly direction along southern shores of Lake Kariba, continuing inside the 1983

treatment area. The operation exhibited the impacts of the technique as indicated by the gradual decline in tsetse populations of both species over the period of the operation. Terrain in the Sengwa river and Umi escarpment areas, in the proximity of the Matusadona hills, was most extreme and rugged, limiting the extent of the aerial spraying to 1 700km<sup>2</sup>. A defense barrier of 3 000km<sup>2</sup>, peripheral to the aerial spraying area was ground sprayed to create a defense barrier to the aerial spray block. Endosulphan was the insecticide of choice at dosages of 25, 18, 14, 14, and 14 g/ha and produced encouraging results. Pupae larviposited by female flies before the commencement of aerial spray accounted for a huge number of flies in category zero. Tsetse dissections were carried out on all female flies captured before and after each spray cycles to determine age structure. After the first application, cycle 1, no females should be older than ovarian category 1 (less than 8 days) if the operation has been entirely successful (Figure 2.8). This was the case for *G. m. morsitans* since no post spray females were found (Table 2.2). However, two parous *G. pallidipes* females, possibly surviving flies, were captured on the Sengwa, where reinvasion did not certainly occur. Both these flies, in category 1, were caught after the third cycle (Table 2.3). This resulted in the endosulfan dosage for final two applications being increased from 14 g/ha to 18g/ha and inter-spray periods kept as short as possible. Usage of low insecticide dosages in the last 3 cycles in 1982 and 1983 was one of the possible reasons for the failure to achieve eradication. However, in 1984, increasing insecticide dosage to 18g/ha in the 4<sup>th</sup> and 5<sup>th</sup> cycles resulted in total eradication of the fly population.

Selective hunting continued in the Tivuli, Lutope and Nagupande area where 177 favoured species were killed. The integrated operation was conducted with the objective of eliminating tsetse south of Lake Kariba. In this operation, 4% DDT WP suspension was used over 2 331km<sup>2</sup> while the SAT operation covered 2 100km<sup>2</sup>. The change from 5% to 4% DDT WP suspension, in 1983, was to lower cost of the operation.

**Table 2.2:** Pre-and Post-aerial spray female *G. m.morsitans* survey data in the Sengwa area in 1984

Ovarian indices	0	1	2	3	4	5	6	7
Pre-spraying surveys	7	2	2	3	4	0	2	2
Cycle 1	24	0	0	0	0	0	0	0
Cycle 2	19	0	0	0	0	0	0	0
Cycle 3	1	0	0	0	0	0	0	0
Cycle 4	0	0	0	0	0	0	0	0
Cycle 5	0	0	0	0	0	0	0	0

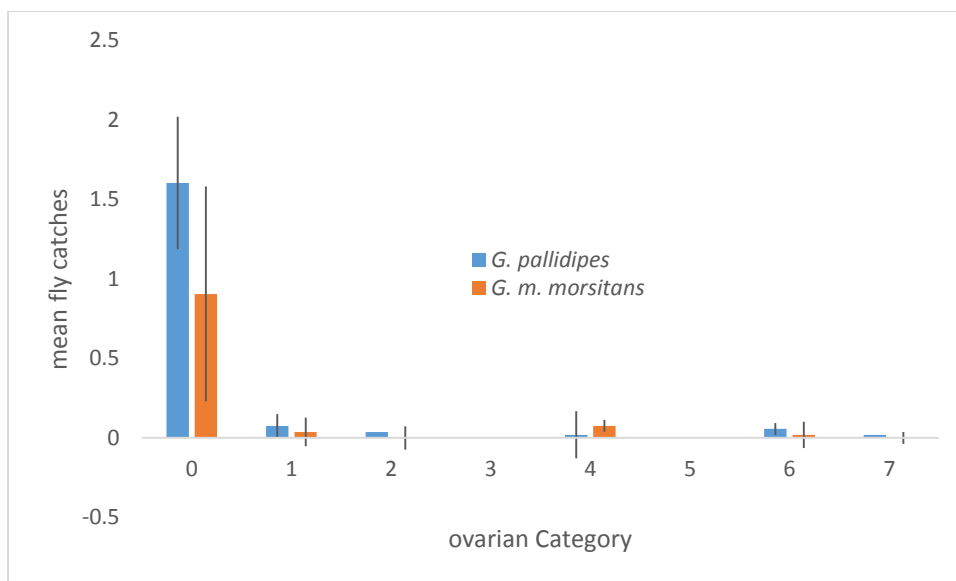
Only teneral female *G. m. morsitans* were caught up to cycle 3. (Source: TTCB Annual report, 1985)

**Table 2.3:** Pre-and Post-aerial spraying female *G.pallidipes* survey data in the Sengwa area in 1984

Ovarian indices	0	1	2	3	4	5	6	7
Pre-spraying surveys	12	4	10	4	15	14	8	6
Cycle 1	35	2	0	0	0	0	2	1
Cycle 2	30	0	0	0	0	0	0	0
Cycle 3	15	2*	0	0	0	0	0	0
Cycle 4	1	0	0	0	0	0	0	0
Cycle 5	0	0	0	0	0	0	0	0

Source: TTCB Annual Report, 1985

Two parous, 2\*, females, both *G. pallidipes* in category 1, were captured on the Sengwa river, where reinvasion did not occur, after the third cycle.



**Figure 2.8:** Post spray dissection, Sengwa survey area, cycle 1 to cycle 5. The error bars are at 95% confidence interval. The samples size was 44 for *G.m. morsitans* and 88 for *G. pallidipes*

Results in Table 2.2 and Table 2.3, above, imply that the insecticide (endosulphan) did not act in a density dependent manner (Knipling, 1979). However, pupal population in 1984 was dense and the number of emerging flies was correspondingly high after the first two applications. This meant more rapid contact between males and females with a consequent shortening of the time to mating and ovulation. A combination of rapid ovulation and speedier larval development, due to increasing temperatures, in 1984 may therefore have resulted in the presence of heavily pregnant females by the time cycle 3 commenced and the 14 g/ha was a sub-lethal dose for the more tolerant female flies. A scenario similar to 1983 recurred in 1984 and the technique did not yield satisfactory results and was less successful as old female tsetse, predominately *G. pallidipes* and *G.m. morsitans* were captured using VET on the Bumi transect after the first cycle. Ten old flies ‘survivors’ were captured close to the boundary of the aerial spraying block and major road, possibly due to reinvasion.

Entomological surveys conducted from late 1984 to early 1985 revealed low tsetse densities throughout the northern half of the 1985 treatment area and a very heavy density, mainly *G. m. morsitans*, further east, between the Omay and Sebungwe Communal lands. Rather than re-treating a number of small residual populations, it was considered more appropriate to treat those parts of the 1984 spray block which were still infested together with the adjacent,

densely infested Sebungwe area, south-east of the Matusadona National Park, in a single operation.

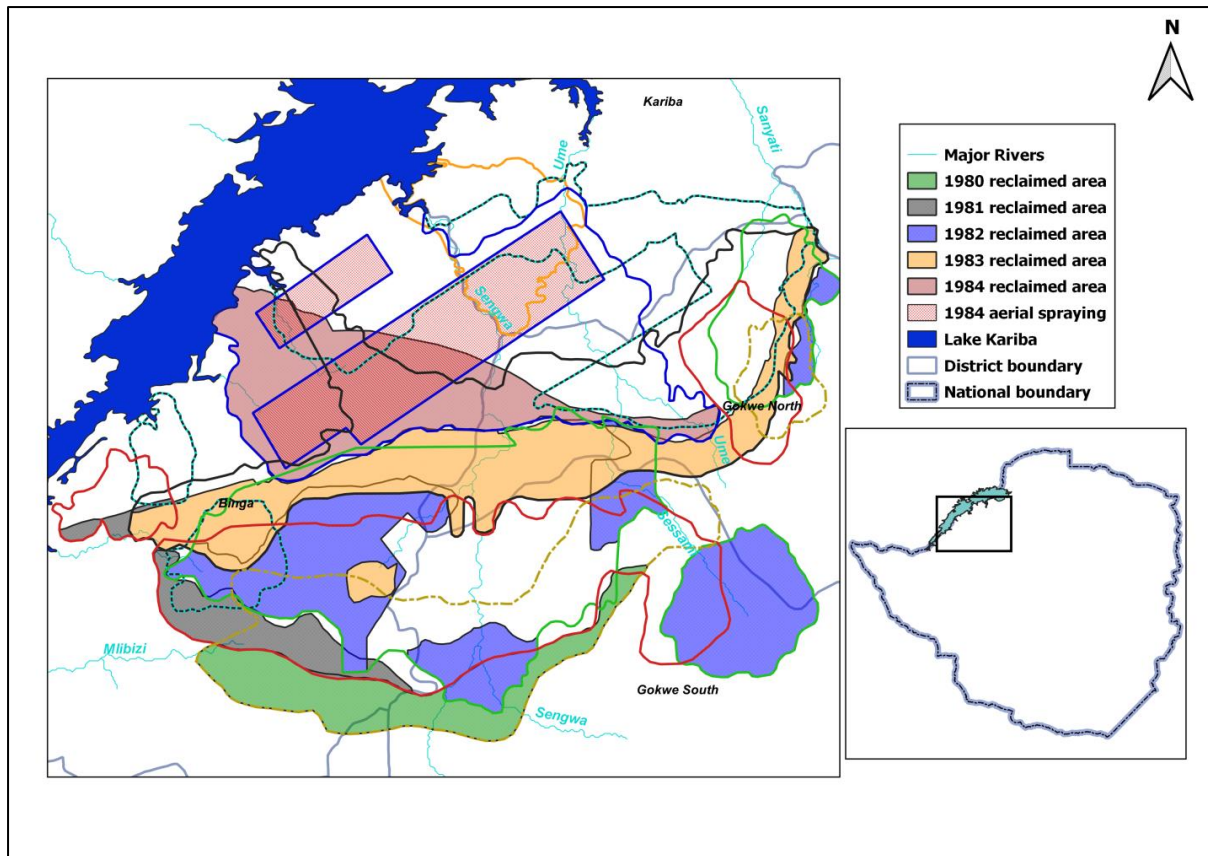
The 1985 SAT operation was undertaken in the north and south blocks measuring 648 and 1033km<sup>2</sup> respectively with an area measuring 4 800km<sup>2</sup>, surrounding the two blocks ground sprayed. A line of insecticide treated targets was placed along the northern boundary of the ground spraying to the south of the Matusadona National Park. Siakobvu is an area of rugged terrain where the substantial residual population, mainly *G. pallidipes*, remained after 1984 required attention. The inclusion of this area provided an opportunity to assess the capability of fixed wing spraying in known 'difficult' areas after appropriate modifications to the technique used the previous year. In particular these included reverting to use of higher insecticide dosages per hectare and avoiding the higher temperature experienced the previous year after starting late.

The southern block, in an area of mopane woodland and moderately undulating terrain, overlapped part of the 1984 ground spraying but also included an extremely high density of *G. m. morsitans* which had not been previously been treated. The presence of a high tsetse population density to the north of the treatment area provided an ideal opportunity to test the effectiveness of impregnated targets as a barrier to reinvading flies. These were tested in a 600km<sup>2</sup> block and the results were encouraging.

Despite various modifications and a reduced tsetse population in the 1984 spray block, aerial spraying still failed to eliminate *G. pallidipes* from the Siakobvu valleys. One theory to explain this failure was that lack of air movement throughout the night in the Siakobvu valley may have reduced the impaction efficiency of drifting droplets. Siakobvu valleys which had very rugged terrain approximately 100km<sup>2</sup> were eventually ground sprayed and the entire northern aerial spraying block was free of tsetse. Authorities decided to use ground spraying and target techniques in the area. Helicopters were used for selective retreatment of difficult, rugged features such as river valleys and escarpments.

#### ***2.2.4.4 Reclamation of land from tsetse infestation in ground sprayed areas***

Map 2.4 clearly depicts areas that were reclaimed following ground spraying operations conducted from 1980-1984. Clearly, large areas were reclaimed during the 5 year period.



**Map 2.4:** Areas Reclaimed in DDT Ground Sprayed Areas: 1980-1984

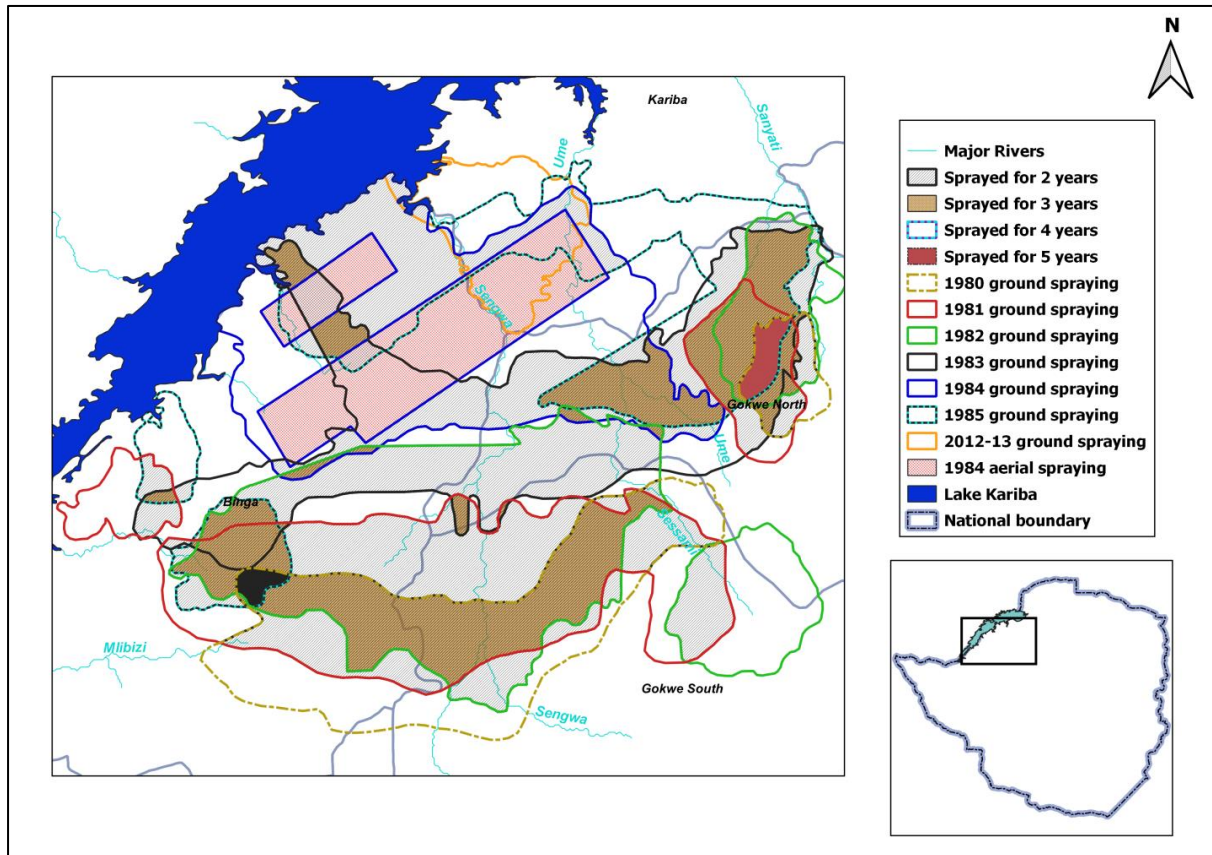
**Table 2.4:** Areas reclaimed by Ground Spraying: 1980-1984

Year	Approx area ground sprayed (Km <sup>2</sup> )	Approx area reclaimed (Km <sup>2</sup> )	% area reclaimed
1980	4 200	1 200	28.6
1981	6 000	800	13.3
1982	7 200	3 500	48.6
1983	5 500	2 600	47.3
1984	3 500	2 300	65.7
Total	26 400	10 400	39.4

Table 2.4 shows that, overall, ground spraying operations reclaimed large areas during the period 1980-1984. However, this large area achieved was not eradicated in one spray operation. An area had to be sprayed at least twice or even three times to eradicate the fly with only 13% having been eradicated in 1981. An area of 26 400km<sup>2</sup>, in Table 2.5 above, is

more than the area actually covered in the 5 years of ground spraying as most of the areas were resprayed.

*Repeated application of ground spraying to clear tsetse from infested areas*



**Map 2.5:** Areas resprayed with DDT in NW Zimbabwe: 1980-1985

**Table 2.5:** Frequency of ground spraying operations 1980-1984

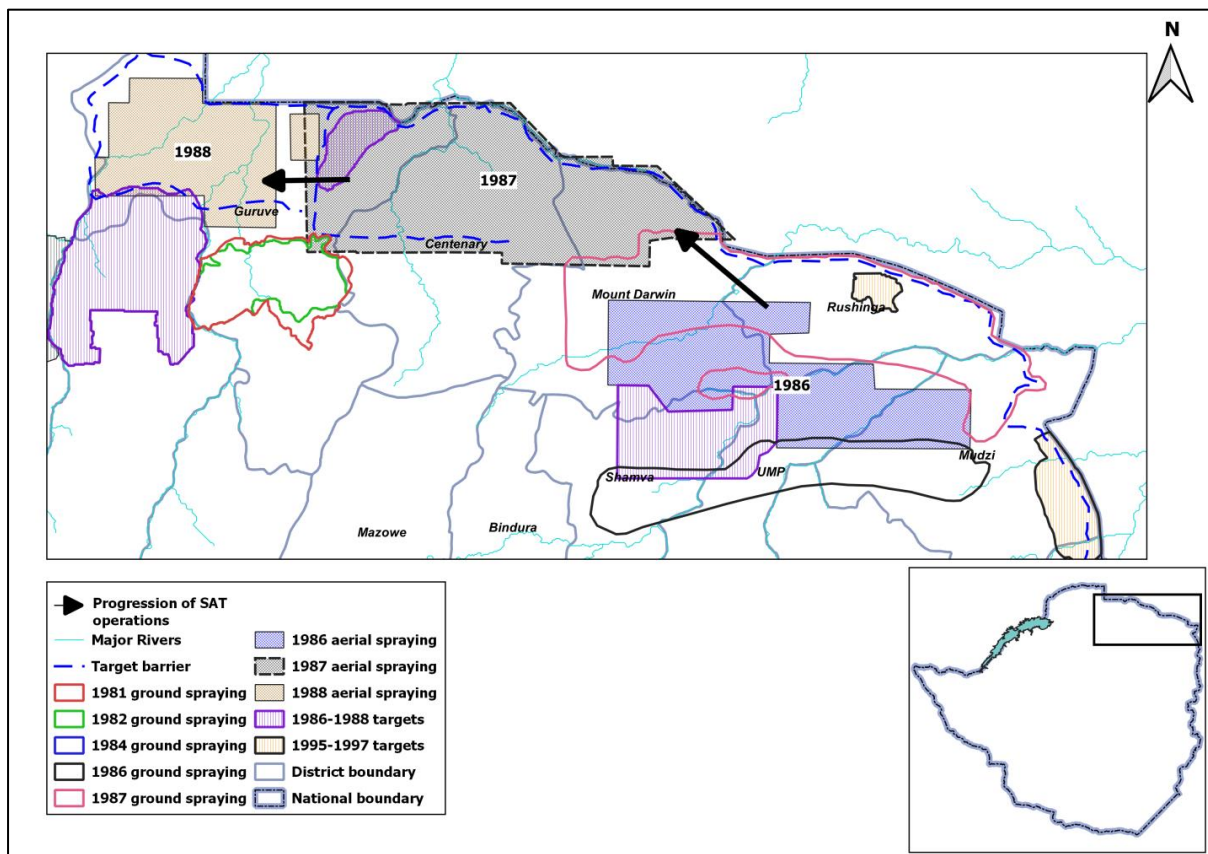
Number of sprays	Approx area sprayed/resprayed (Km <sup>2</sup> )	Sprayed/resprayed area as % of total area (26 400 Km <sup>2</sup> ) sprayed
1	4 700	17.8
2	12 800	48.5
3	5 800	21.9
4	70	0.3
5	130	0.5

Map 2.5 and Table 2.5 above shows the number of times different sections, of the 26 400km<sup>2</sup> was sprayed/ resprayed from 1980 to 1985, to clear tsetse. Only 17.8 % of the total area sprayed once to the point of clearing tsetse while 82.2% had to be repeated at least twice. Nearly half of the area (48.5%) was treated twice while less than 1% was sprayed 4 or 5 times.

#### 2.2.4.5 North East Zimbabwe

Attention, in the implementation of tsetse control programmes, was shifted from the NW to the NE following an upsurge in AAT cases and reported cases of cattle deaths due to the tsetse-transmitted trypanosomiasis.

##### 2.2.4.5.1 Progression of tsetse control programmes in NE Zimbabwe



**Map 2.6:** Tsetse Control Operations in Northern and NE Zimbabwe: 1981-1997

The Regional Tsetse and Trypanosomiasis Control Programme (RTTCP), funded by the European Commission, was commenced in 1986 in NE Zimbabwe. Operations were commenced in the Chesa farming area in 1986 using a mosaic of ground spraying, aerial spraying and DDT-treated targets. The Zambezi Valley escarpment area, in Umfurudzi

National Park, and affected farming areas covering 3 200km<sup>2</sup> were aerial sprayed in 1986. Spraying operation was a resounding success due to the flat terrain and low fly densities. The incidence of trypanosomiasis in the farming area decreased rapidly to zero. A similar operation was conducted in 1987 with the aerial spraying block measuring 4 700km<sup>2</sup> and located in the Zambezi Valley escarpment near Mozambique border (Map 2.6). The aerial spray block was protected by a barrier of targets and a DDT barrier of ground spraying in the south. This operation covered Muzarabani, Mukumbura and Chiswiti communal lands and eastern part of Dande communal lands. Tsetse densities in the block varied from low to high with the main species being *G.pallidipes* found in the northwestern corner of the block and along the foot of the escarpment. The operation achieved eradication of *G.m.morsitans* throughout the block. However, *G.pallidipes* proved again to be receiving sub-lethal doses of the insecticide following capture of survivors and a sixth application of insecticide was made over the western third. No changes in species density were recorded indicating failure of the operation.

The 1988 aerial spraying operation had two specific objectives of tsetse eradication and research on the effectiveness and environmental acceptability of deltamethrin as a potential alternative to endosulfan. The operation served as a large-scale field trial for deltamethrin thus executing the third and final stage of the RTTCP protocol for evaluating insecticides for aerial spraying. The spray block, of 2 000km<sup>2</sup>, was located immediately north of the escarpment within the drainages of the Angwa and Manyame rivers. Post and during spray survey results indicated that the deltamethrin was highly effective against heavy infestation of *G. m. morsitans* present, resulting in an apparent reduction of this species within the block. However, the operation was not effective against *G. pallidipes* population after 5 cycles, eradicating 99% of this species flies. The 1% remnant flies required retreatment of the area with other techniques, to achieve total eradication.

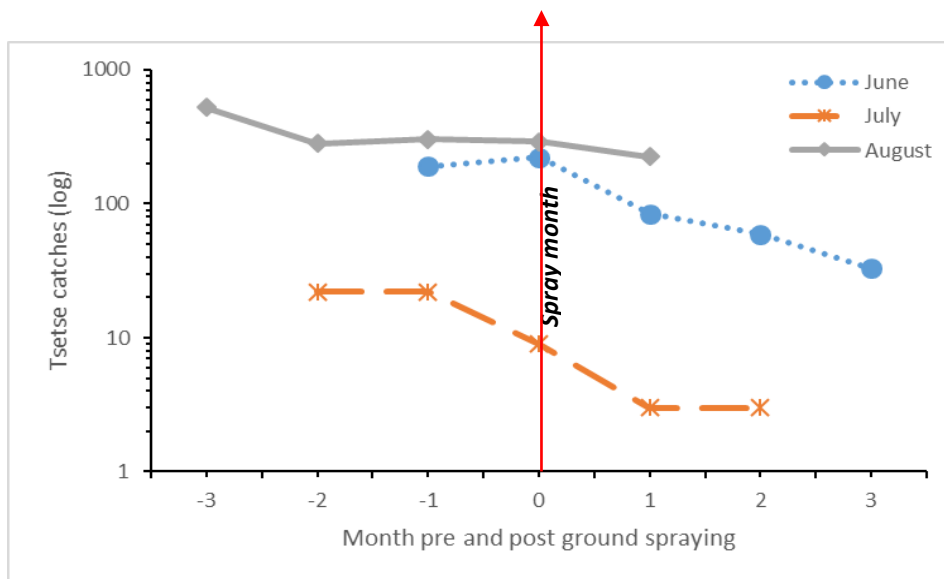
The 1987 and 1988 operations were less successful than the 1986 operation in the Umfurudzi area. It had been resolved to stop the aerial spraying in view of the unsatisfactory results in 1988. However, Vale, who was the Assistant Director for TTCB and Project Manager of RTTCP Zimbabwe, decided to pursue scientific research on the results from the operation. The trial gave enough evidence to support the claim that deltamethrin was equally efficient in eliminating tsetse populations at a recommended dose as endosulfan. The levels of percentage control of each species in 1988 were much the same as those produced using

endosulfan in a nearby block in 1987. The Scientific Environmental Monitoring Group (SEMG) monitored effects of the insecticide on non-target organisms and concluded that deltamethrin could be used as an alternative insecticide to endosulfan in any future aerial spraying that might be conducted by the RTTCP. Additionally, deltamethrin would be the preferred insecticide when operations were near large bodies of water. The last aerial spraying operation, in the country, was conducted in 1988. This was after the levels of success of the operations had reduced drastically as the terrain became more broken.

Large-scale ground-spraying was conducted against *G.m.morsitans* in the area during the 1986 and 1987. The first operation was aimed at protecting the 1986 aerial spraying block from reinvasion and covered large area of hilly country and limited area of flat terrain. The second operation was aimed at eliminating of tsetse from vast area of infested, very hilly country of limited areas of flat terrain in the north and east of the 1986 block. The 1987 also reduced the occurrence of trypanosomiasis in Kandeya communal land in the area immediately to the north of the Umfurudzi target operation. The insecticide used was DDT 4% WP suspension. No tsetse could be found in the treated areas following ground spraying as demonstrated by survey results. Another indicator of success was the drastic reduction of trypanosomiasis cases in the ground sprayed operational area.

#### ***2.2.4.5.2 Doma ground spraying operation: 1981***

Ground spraying operation in Doma, 1981, was conducted using a 4% DDT WP suspension at 469litres/km<sup>2</sup> or active ingredient application rate 18,76g/km<sup>2</sup>. The cost of the application was \$170/km<sup>2</sup>, inclusive of salaries and subsistence for graded staff, labour wages and rations, transport and insecticide. Results obtained are shown in Figure 2.9, below.



**Figure 2.9:** Ground spraying operation in Doma area: 1981

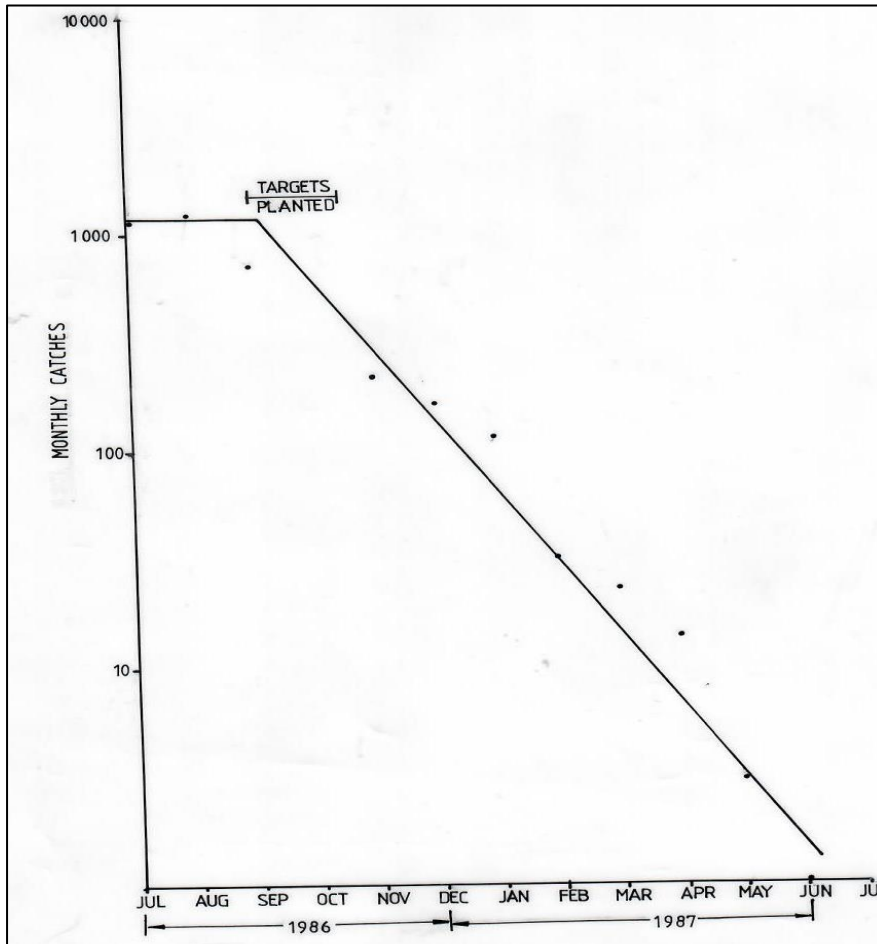
Tsetse catches for 3 months after June ground spraying operations indicated a considerable decline in fly populations. During the first month following the July operation, tsetse populations fell sharply and no changes were apparent afterwards. Trap surveys following the August ground spraying also indicated a decline in tsetse catches. There was need to repeat spray applications following application of this ground spray operation.

Targets were also used in Umfurudzi alongside ground spraying and worked very well. During that time, an experiment to see how ITC alone performs was undertaken. In this context, the 350km target barrier from the Matisi River in Nyanga North to Musengezi River to the west was uplifted to assess the effectiveness of cattle dipping with deltamethrin as a barrier against tsetse invasion. Disaster ensued with flies invading from across the border thereby putting cattle at risk of contracting AAT. In response, the barrier was quickly redeployed and the situation restored. However, the long lasting solution to the tsetse problem in this region was to carry out joint eradication operation with Mozambique.

#### **2.2.4.5.3 Umfurudzi Target Operation, 1986**

Following success with targets in the Rifa triangle, a target operation was undertaken in the Umfurudzi resettlement area, measuring 1 300km<sup>2</sup>. To the North and East, the target treated area adjoined the 1986 ground spraying block, to the south, it linked with the ground sprayed areas and to the west of the block was believed to be tsetse free. Figure 2.10 shows a

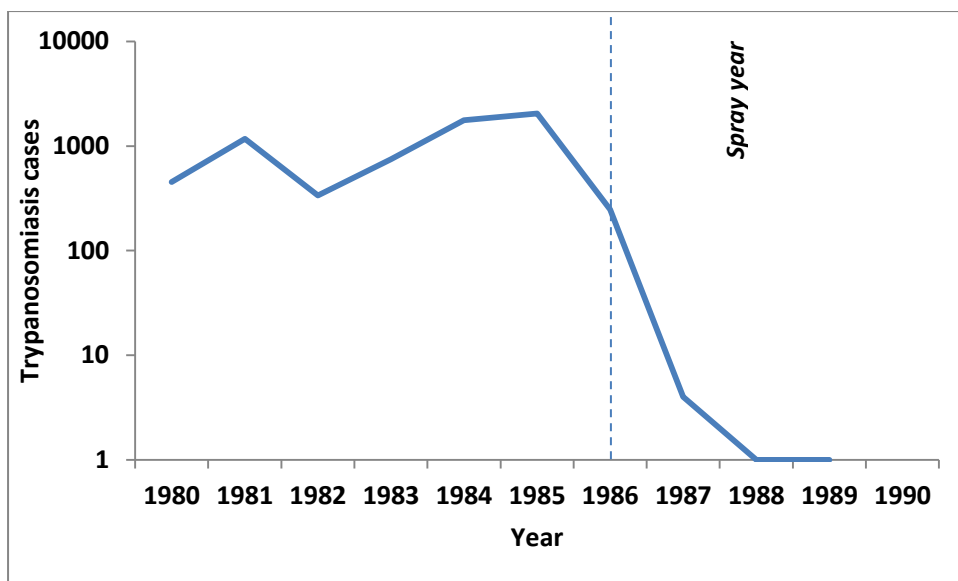
reduction in tsetse population from initial levels of over 1 000 tsetse per month to no catches after 9 months following the deployment of targets.



**Figure 2.10:** Tsetse flyround catches in the targeted area in Umfurudzi, NE Zimbabwe: 1986  
 A decline in trypanosomiasis cases was apparent with a drop from over 200 cases in 1986 to only 14 a year later (Lovemore, 1999) and to zero catches by 1987. No incidences of trypanosomiasis were recorded after 1987.

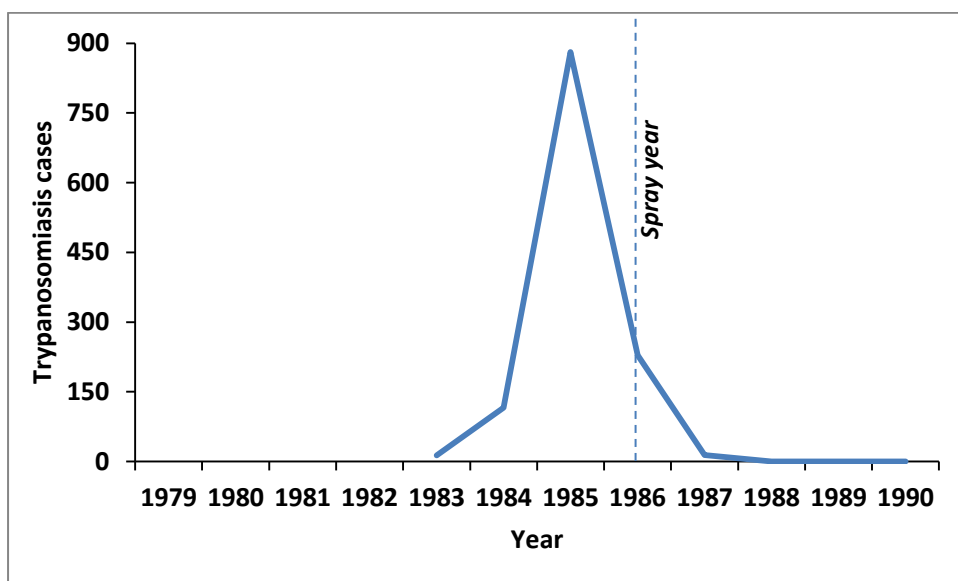
**2.2.4.5.4 Impact of aerial spraying in Chesa small scale farming area and Umfurudzi resettlement area, 1986**

In the 1986 aerial spraying operation, endosulphan was applied in all the 5 cycles at a dosage rate of 22, 18, 14, 14 and 14g/ha respectively. No surviving tsetse were found immediately after the operation.



**Figure 2.11:** Changes in trypanosomiasis cases following aerial spraying in Chesa

Trypanosomiasis incidence significantly declined in the subsequent years. By 1988, cases had declined from more than two thousand to one (Figure 2.11). Similarly, trypanosomiasis incidence declined to zero in the Umfurudzi operation (Figure 2.12).

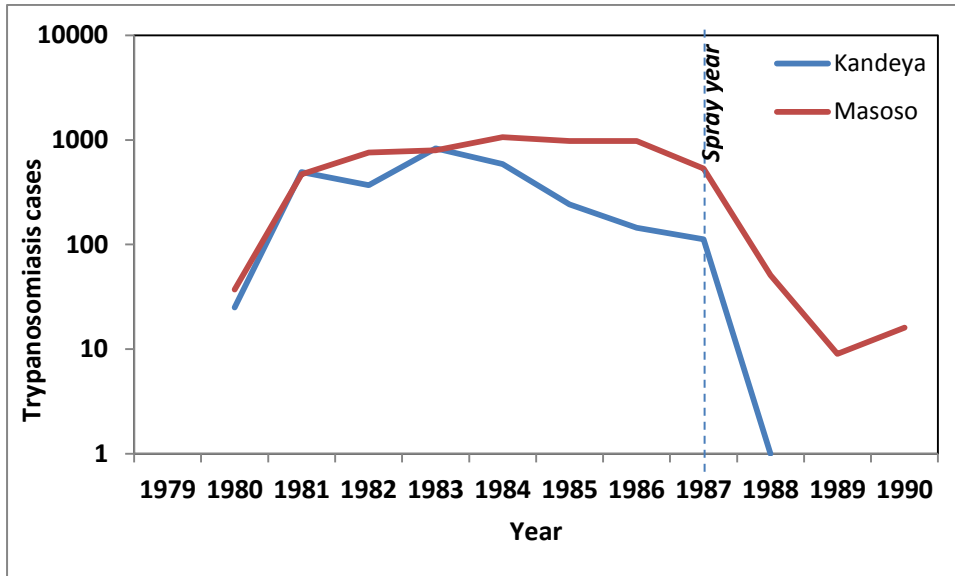


**Figure 2.12:** Changes in trypanosomiasis cases following aerial spraying in Umfurudzi resettlement area

#### 2.2.4.5.5 *Ground spraying in Kandeya and Masoso Comunal lands, 1986*

The main purpose of the ground spraying, covering 3 917 km<sup>2</sup> operation was to clear tsetse from extensive areas of infestation, in very hilly country and limited areas of flat terrain which could not be aerial sprayed. It also protected the adjacent aerial spraying block from

reinvasion and overlapped 1986 aerial spraying block in two places in response to trypanosomiasis occurrence in Kandeya Communal Land, immediately to the north of Umfurudzi target operation. Insecticide used in the operation was DDT (4% suspension of active ingredient).



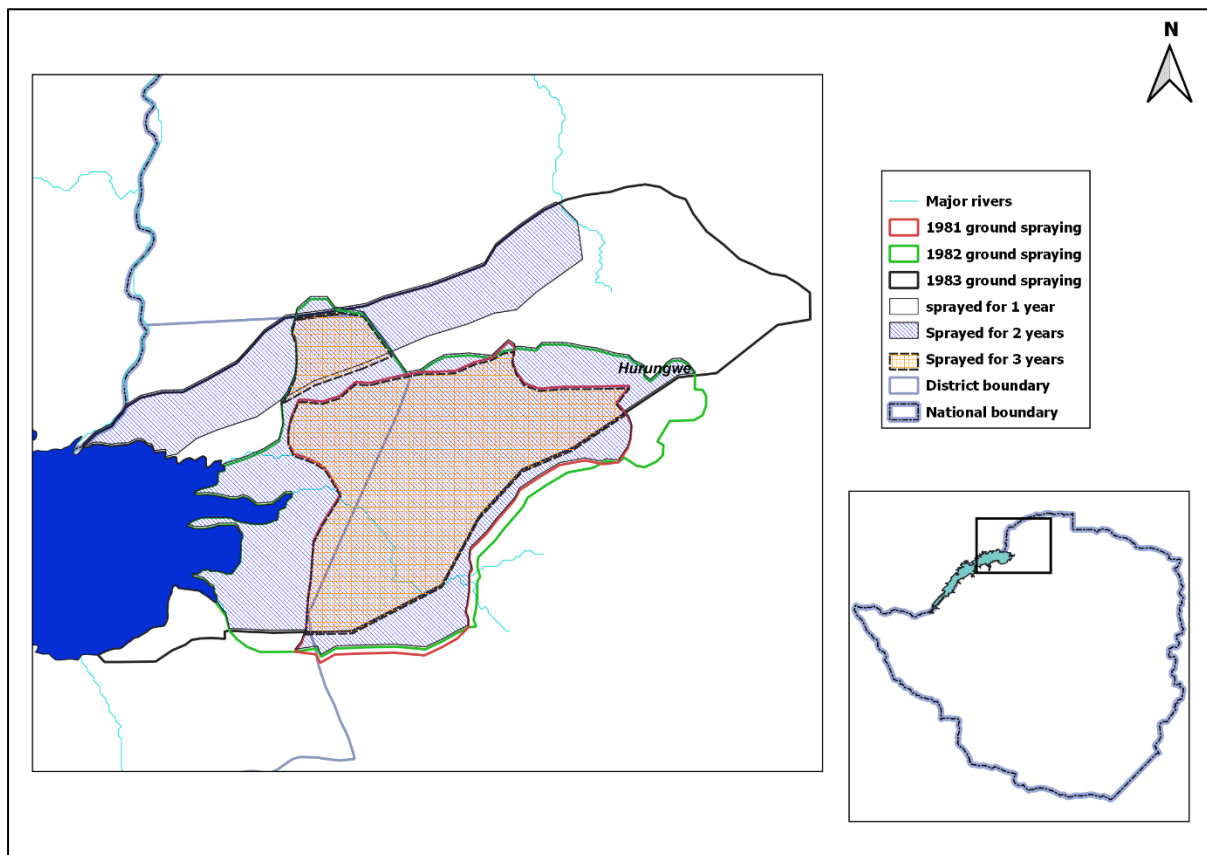
**Figure 2.13:** Changes in trypanosomiasis cases in ground sprayed communal areas

A sharp decline in trypanosomiasis cases was noted following the ground spraying operation in Kandeya and Masoso communal lands (Figure 2.13). However, in Masoso communal lands at the edge of the spray block, few sporadic cases of trypanosomiasis were still detected in subsequent years.

#### **2.2.4.6 Northern Zimbabwe**

Tsetse operations were conducted in the Northern districts in Vuti, Mukwichi, Hurungwe and Doma (Map 2.7) in the 1980's to progressively reclaim land that had been lost to tsetse invasion during the war and to push the fly front towards the international border with Zambia.

### 2.2.4.6.1 Ground spray areas in Northern Zimbabwe



**Map 2.7:** Frequency of ground spraying to clear tsetse in N Zimbabwe: 1981-1983

**Table 2.6:** Frequency of ground spraying operations 1980-1983

Number of sprays	Area sprayed/resprayed (Km <sup>2</sup> )	Sprayed/resprayed area as % of total area (4 800Km <sup>2</sup> ) sprayed
1	1050	21.8
2	2580	53.8
3	1170	24.4

The observation in the ground spraying operations in the Northern region was similar to the trend observed in NW Zimbabwe, where repeated applications of DDT were necessary to completely clear tsetse from a given area (Table 2.6).

#### *Charara ground spraying operations, 1983*

Comparison of ground spraying operations conducted in 1981-1982 using 2.5% DDT along the Charara drainage was less successful than the operation in 1983 with 5% DDT (Map 2.7). However, the dosage can be reduced to 4% and still obtain successful results as in the

Kandeya and Masoso communal areas in NE Zimbabwe as presented in section 2.2.4.5.5 above.

#### **2.2.4.6.2 Target Operation in Northern Zimbabwe**

##### ***Doma target operation, 1988-1991***

A large scale trial operation was carried out in a 2 000 km<sup>2</sup> area between the Angwa and Manyame rivers as a means to eradicate *G. m. morsitans* and *G. pallidipes*. Odour-baited S-type targets fitted with black cloth only were deployed at varying densities, (1- 4/km<sup>2</sup> along river lines and lesser drainage lines, and 30/km<sup>2</sup> in 4 target lines with 133m spacing between targets and lines. No change in *G. m. morsitans* populations was noted where target densities were less than 4/km<sup>2</sup> while 99.3% reduction was recorded for *G. pallidipes*. At 4 targets/ km<sup>2</sup>, *G. pallidipes* population reduced by 99.8% and for *G. m. morsitans* there was no notable change as the deployment was biased towards drainages. Despite rapid reduction in *G. pallidipes* populations, eradication was not achieved.

##### ***Mukwichi target operation, 1993***

In 1992, the Mukwichi river drainage was infested with tsetse and extended to the northern and eastern farms of the Karoi commercial farming area. Tsetse infestation had at this point exceeded the 1 200m contour at an altitude thought to be above their limits (Davison, 1996). A target operation was carried out under the second phase of the RTTCP project in 1993 in Hurungwe district, subsequently named the Mukwichi Target Operation (Map 2.2). A total of 8 481 odour-baited and insecticide treated “S” type targets were deployed in 320 habitat dictated transects over 1 337km<sup>2</sup> of tsetse habitat i.e. at 6 targets per km<sup>2</sup>, above the recommended 4 targets per km<sup>2</sup>. The success of the Mukwichi operation was demonstrated by the decline of trypanosomiasis cases from 55 in 1993 to 2 in 1994 and to zero from 1995-1998.

#### **2.2.4.6.3 Regional collaboration: Zambia and Zimbabwe target operations in cross border operations: Kariba-Siavonga**

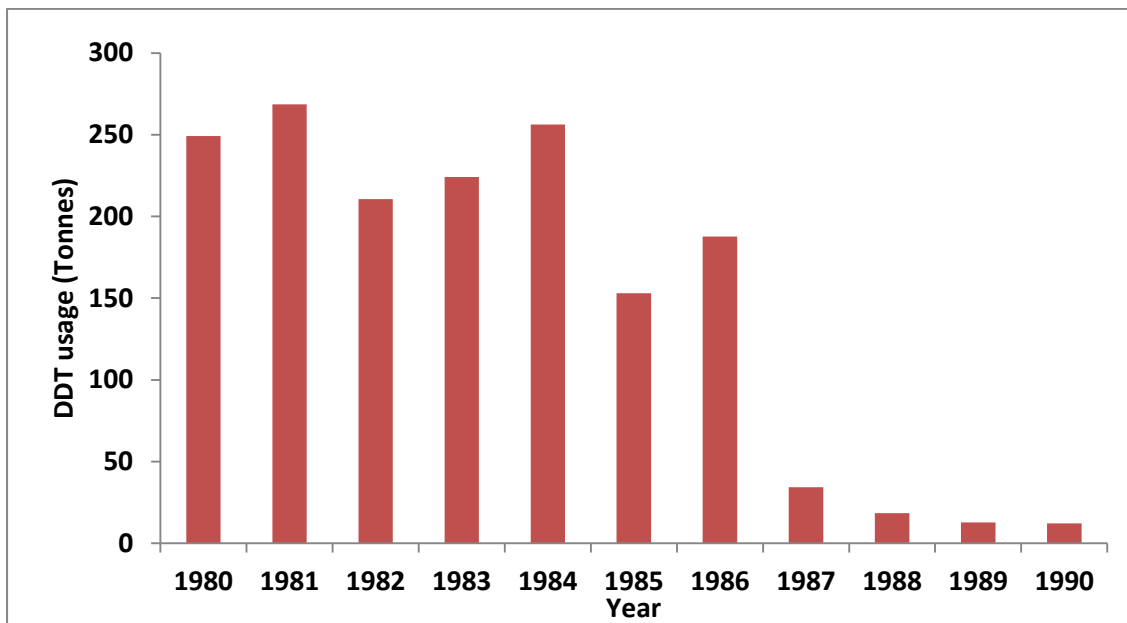
A joint target operation was planned between Zimbabwe and Zambia in the Kariba- Siavonga area. A plan was developed and agreed upon during the RTTCP that Zimbabwe and Zambia would synchronize the deployment of targets so as a strategy to deal with the common tsetse belt between the two countries. The operation was not implemented simultaneously as planned and tsetse started to reinvade Zimbabwe from Zambia. Zimbabwean authorities went

to Siyavonga to investigate the cause for the reinvasion as expectation was that tsetse should have declined in Zambia in a similar manner as in Zimbabwe. Then investigations confirmed that no targets had been deployed in Siyavonga although maps produced were showed that the area had been treated with targets. However, teams manning the operation in Zambia, later confirmed that targets had not been deployed because the Zambian army was running an exercise in the area and they had to defer deployment of the targets to a later time (Vale, pers. comm).

#### 2.2.4.7 South Eastern Region

A ground spraying operation was conducted in in the South–East lowveld area in 1981, and was highly successful. After the operation, there were sporadic AAT cases and no tsetse were caught despite continuous survey effort. There was clearly no need for further vector control measures in 1982.

#### 2.2.5 Phasing out of the use of DDT in ground spraying operations: 1980 to 1990



**Figure 2.14:** Quantities of DDT used to control tsetse: 1980-1990

Figure 2.14, shows how ground spraying with DDT was gradually phased out and completely stopped in 1990, in response to public concern. Usage of the chemical was drastically reduced after development of the target technology as the country switched from the use of other techniques to the use of insecticide- treated targets.

### 2.2.6 Cost of tsetse control operations

**Table 2.7:** Estimated cost of tsetse eradication or control

Technique	Cost/km <sup>2</sup> (US\$)	Objective and location
Ground spraying (Barrett, 1997)	265-315	Eradication, Zimbabwe,
Aerial spraying (SAT) (Barrett, 1997)	345-535	Zambia, flat terrain
Cattle treatment (Barrett, 1997) (pour on, 15 cattle/km <sup>2</sup> )	50-120	
Targets at 1 per sq. km. (Chadenga, 1992)	30-40	Eradication, based on
Targets at 4 per sq. km. (Chadenga, 1992)	75-90	Zimbabwe
Sterile Insect Technique (Feldmann, 2003 pers. com)	800	Eradication East Africa

The most significant study to appear since Swallow's review is the socio-economic volume produced in 2000 by the (RTTCP). This volume (Doran, 2000) is based on socioeconomic surveys and studies done in all four RTTCP countries, and concludes: "The evidence available from these studies suggests that the continued use of trypanocides to control the disease is the most sustainable and transferable option available at present for Malawi, Mozambique and Zambia. In Zimbabwe, the logical strategy is to hold the target barrier to prevent re-invasion of tsetse flies from neighbouring countries." The socio-economic study is based on a cost-effective and reproducible methodology and survey questionnaires. An assessment of the costs associated with each technique has been compiled in Table 2.7.

### 2.3 Discussion

The strategic and tactical approaches used in Zimbabwe have provided critical lessons on how tsetse control programmes can be planned and executed in future. Selection of the most appropriate technique is key to achieving the desired results. Eradication of tsetse from vast areas in Zimbabwe resulted from support by strong research unit that constantly looked at improving and developing new cost effective techniques and resource mobilisation from both Government and development partners. Among the wide range of techniques available, bait systems (insecticide treated targets and cattle) have emerged as the most preferred options which are currently in use in Zimbabwe and in many other countries in Africa as they are low-tech and cost-effective. Historical perspectives of approaches adopted in Zimbabwe are

testimony to the success in tsetse control programmes which were based on either holding the line to stop tsetse invasions or progressive eradication to reclaim more land from tsetse infestation. No one control measure is appropriate in all situations hence the need to integrate techniques.

Lesson learnt from the Zimbabwean experience is that reinvasion is a major drawback in all tsetse control programmes. For example, all land cleared in NE Zimbabwe was lost to the ecological limit when operations were either been stopped or scaled down during the war. Further, 1500km<sup>2</sup> of cleared areas was lost to tsetse reinvasion in 2018, in Omay Communal land, NW Zimbabwe. There is risk of the country losing more areas to reinvasion as some areas are becoming ecologically suitable for tsetse due to climate change (Lord *et al.*, 2018). The loss of cleared areas can be averted by the use of target barriers.

### **2.3.1 Aerial Spraying**

Aerial spraying was the most rapid and ideal technique used in trypanosomiasis epidemic situations and was the technique of choice to reclaim areas that had been reinvaded by tsetse during the war years in Zimbabwe. Experience in Zimbabwe demonstrated effectiveness and limitations of aerial spraying. SAT became less effective as the operations progressed from flat to more rugged hilly terrain that was infested by higher densities of *G. pallidipes* and therefore exposed to higher invasion pressure. The technique is less effective in hilly terrain because the insecticide droplets are not evenly deposited (Hursey and Allsopp, 1983) due to the catabatic winds which interfered with the impaction of droplets. Lesson learnt in aerial spraying operations conducted from 1982 to 1985 was that efficiency of operations declined in as the programmes were shifted from flat terrain to the hilly and broken terrain. Situation was exacerbated by the presence of *G. pallidipes* at higher densities. In Botswana where the terrain in the Okavango delta is flat, aerial spraying operations in the mid-2000 resulted in total eradication of tsetse (Kgori, Modo and Torr, 2006). One of the lessons learnt was that success of aerial spraying hinged on 3 key principles that i) the spray duration should cover the entire pupal period of tsetse and ii) each cycle should target to kill all the adult flies particularly the females and iii) no females should develop to the stage of dropping larva before the application of the next cycle as this would shift the pupal period. This would necessitate extension of the spray period making the operation more costly or the desired result would not be achieved. For example, there was need for an additional spray cycle during the 1985 SAT operation, in NW Zimbabwe. One of the demerits of aerial spraying is

that it requires protection against tsetse reinvasion. Lesson learnt is that aerial spraying works best in a ‘mosaic’ along with other control techniques such as ground spraying or targets protecting the aerial spraying block, as for example the integrated operation in 1986 in Umfurudzi area in NE Zimbabwe. However, the protection needed for an aerial spraying block implies treating a large area with either targets or ground spraying. For example a 4000km<sup>2</sup> aerial spray block measuring 20x200km would require a 4800km<sup>2</sup> protection barrier of targets, 10km wide, making the technique even more costly. Insecticide dosage is critical in aerial spraying operations hence lethal doses should be applied. For example, lesson learnt from the 1984 spraying operation in NW Zimbabwe was that 14g/ha of endosulfan was insufficient to kill heavily pregnant female *G. pallidipes* and the dosage had to be increased to the 18g/ha. Generally, female *G. pallidipes* are more resistant to the insecticides used than *G. m. morsitans*.

### **2.3.2 Ground Spraying**

Lesson learnt on selective and discriminative ground spraying in Zimbabwe is that both riverine woodland and open deciduous woodland should be sprayed. This approach was in line with the concept of random tsetse movement by Bursell (Bursell, 1970) that was opposed the “home” and “feeding ground” theory and directional tsetse movement (Jackson, 1941, 1944). This approach targets both *G. m. morsitans*, which tend to be more widely spread in both vegetation types (Pilson and Pilson, 1967) and *G. pallidipes* which tend to be more widely confined to the riverine areas during the hot and dry season (TCD annual report, 2012). In the present study, one of the lessons learnt was that failure of the ground spraying technique to clear tsetse in a single operation may be related to the build-up of the tsetse population after insecticide residual deposits are washed off by the rains before implementation of the next dry season ground spraying operation in the following year. Subsequent ground spraying operations will result in a further reduction of the tsetse population and residual pupae in the ground will not sustain a fly population on emergence. This may be the basis of success of ground spraying operations in areas of low tsetse densities as experience has shown. Repeated sprays are necessary in areas of high tsetse densities. The scenario was worse in the past when ground spraying was conducted in riverine areas only as there was lengthy delay phase in tsetse getting into contact with treated surfaces during the hot dry season.

While ground spraying was the mainstay of tsetse control in Zimbabwe till 1980, the technique began to be de-emphasised from 1980-1990 due to the negative impacts of the organochlorines used. One other factor that led to ground spraying being de-emphasised was its demand for huge logistical support in the form of lorries, landrovers and labour force. Ground spraying was therefore replaced by other more environmentally accepted techniques such as aerial spraying and bait technology. It is, however, true that effects of DDT were overplayed by conservation pressure groups as confirmed by the DFID-funded DDT Monitoring project in 1998 (DFID, 1998). The technique has, however, been kept as an acceptable option for tsetse control through the use of the less hazardous and biodegradable pyrethroid, deltamethrin. Although suitable as a replacement for DDT, deltamethrin doubled the cost of ground spraying per unit area (Chadenga, 1992).

### **2.3.3 Bait technology**

Bait technology has become the most preferred as it is environmentally friendly, simple to use and low cost technique (Vale *et al.*, 1988). In addition, the technology has offered an effective means of protecting cleared areas against tsetse invasions in programmes where barriers of targets, complemented by dipped cattle, as shown in Map 2.2 have been used (Warnes *et al.*, 1999). Insecticide treated cattle remains the cheapest (Chadenga, 1992; Barrett, 1997) tsetse control methodology and is applicable where cattle exist in sufficient numbers (Warnes *et al.*, 1999) provided there is buy-in from the farmers in supporting the cattle dipping/ treatment programme and management of AAT through the use of trypanocides. Lesson learnt from bait technology is that ITT and ITC will impact on tsetse populations at similar rates and can easily be integrated in a “mosaic” situation without the risk of tsetse reinvasion from one area to the other. In terms of their performance, targets are capable of eradicating tsetse from an area within 9 months if well maintained. This finding is consistent with the results obtained in the Rifa triangle small scale target trial (Vale *et al.*, 1988). Lesson learnt from the Doma experience is that targets need to be deployed in accordance with the Standard Operating Procedures to produce desired results. Fly situation in Doma did not change mainly because no targets were deployed in appropriate places.

Although huge successes were realised in the collaborative RTTCP, multinational programme of Malawi, Mozambique, Zambia and Zimbabwe, a number of shortcomings in implementation were observed. For example, member countries planned and implemented their programmes in isolation. An attempt was however made to synchronise operations in

the Kariba and Siyavonga areas of Zimbabwe and Zambia respectively. Lesson learnt this joint programme was that cross border joint operations must be conducted simultaneously to avoid the risk of tsetse reinvasion from one country to another.

## **2.4 Conclusion**

The four decades of tsetse control in Zimbabwe (1980-2019) has been a period to understand determinants for success in tsetse control campaigns and important lessons had been learnt which are important for decision making in future.

Choice of control technique was based on the objective of the project. Where there was need for rapid elimination aerial spraying was more appropriate while in cases where progressive eradication was the objective, aerial spraying, ground spraying, ITT or ITC were applied. For isolated tsetse populations, SIT or SAT is most suitable.

ITC was the cheapest method of tsetse control, in places where cattle occurred in sufficient number (Warnes *et al.*, 1999). It was highly effective at preventing invasion (Van Den Bossche *et al.*, 2001). Targets are the second least expensive tsetse control technology followed by ground spraying and aerial spraying. SIT was by far the most expensive and requires a lot of technical and logistical support. Of the affordable options, the choice of which particular option to adopt depends on whether eradication or control is required, the concern for the environment, the type of terrain, the extent to which invasion is likely to occur. Reinvasion into tsetse cleared areas can, however, now be restricted through the use of barriers of targets complemented by ITC.

## **2.5 Future prospects for tsetse control in Zimbabwe**

1. Regional collaboration for Area-Wide, Integrated Pest Management (AW-IPM) to effectively deal with transboundary common tsetse flybelts than control by individual countries in isolation.
2. Using predictive models to plan tsetse control operations.
3. For sustainability, tsetse control programmes will be aligned with National Development programmes and will target areas of high AAT and *rhodesiense* HAT (*r*-HAT) prevalence.

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**Chapter 3 : Development of an atlas of tsetse and animal African trypanosomiasis for  
Zimbabwe**

### 3.1 Introduction

This is an epidemiological chapter based on the compilation of entomological and parasitological data. The epidemiological distribution pattern of tsetse-transmitted trypanosomiasis in Zimbabwe is closely related to the spatial distribution of tsetse flies. While other biting flies such as *Stomoxys* and Tabanids are found in Zimbabwe, mechanical transmission of trypanosomiasis has never been proven as a serious problem in Zimbabwe and accounts for a negligible proportion of the cases recorded in livestock.

The Division of Tsetse Control Services (TCD) is responsible for management of the tsetse vector and compilation of disease data while the role of the Veterinary Services is management of diseases including AAT, and operation of diptanks. TCD conducts tsetse surveys in all areas within the tsetse belt regularly to establish tsetse abundance and distribution. Only 2 tsetse fly species, *Glossina morsitans morsitans* and *Glossina pallidipes* occur in the Northern and North Western districts of Zimbabwe (Shereni *et al.*, 2016) over approximately 31 500km<sup>2</sup>. Interestingly, AAT distribution follows quite closely the distribution of tsetse unlike in other countries like Sudan where mechanical transmission by other vectors like tabanids and stomoxys as well as animal movement e.g. pastoralism brings the disease far beyond the tsetse infested belt (Ahmed *et al.*, 2016; de Gier *et al.*, 2020). In Zimbabwe, however, no evidence of mechanical transmission was found in the SE of the country (Boyt, Mackenzie and Ross, 1970).

The present distribution of tsetse and AAT in Zimbabwe is the result of a long and complex history with an interplay of epidemiological, environmental (e.g. climatic and landcover) and disease control factors. It was in the 1980s-1990s, when major tsetse control operations were implemented in Zimbabwe and freed large areas of AAT (Shereni, 1990; Lovemore, 1994). Since the year 2000, resources for large scale operations decreased and the focus of operations was mostly on the maintenance of the gains made in previous periods.

In addition to AAT, Zimbabwe also reports cases of HAT (*rhodesiense* form). The cases are reported from a relatively circumscribed focus in Hurungwe district in the northernmost part of the country (Shereni *et al.*, 2016). Tsetse and AAT control in Zimbabwe are responsibilities of the Division of Tsetse Control Services and the Division of Veterinary Services respectively.

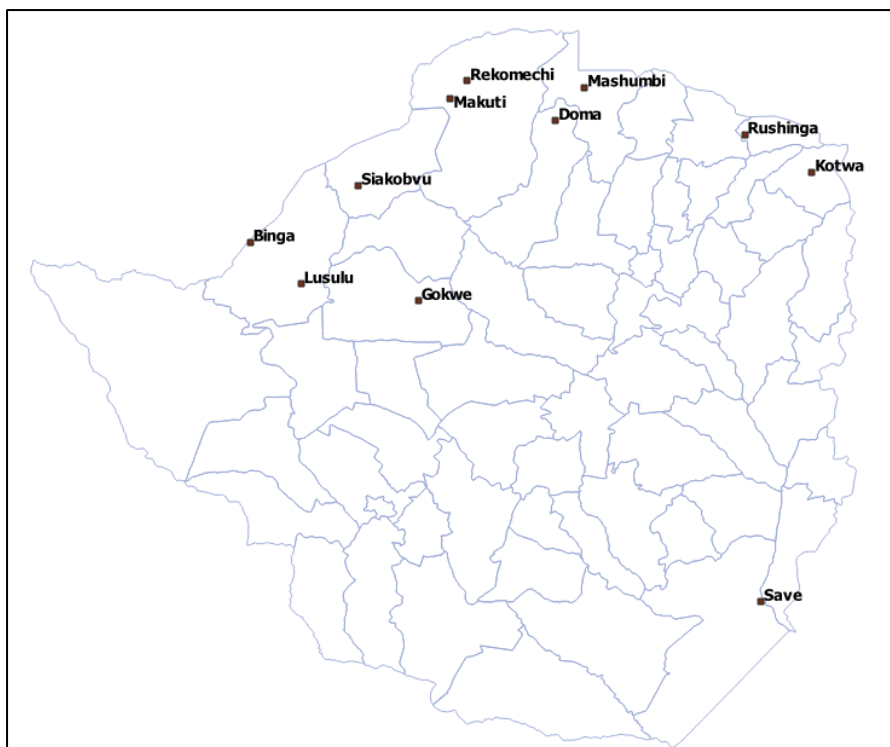
The last National map of trypanosomiasis distribution in Zimbabwe was published in 1999 (Van den Bossche and Vale, 1999). The gap meant to be addressed in this paper is the lack of an information system or database on tsetse and AAT. This gap exists despite the fact that substantial monitoring data have been collected for years by the unit. Procedures for data management and data flow existed but there was no centralized database such that the data were scattered, not harmonized and therefore prevented certain types of analyses to be conducted. The FAO continental atlas (Cecchi *et al.*, 2014, 2015) of tsetse and AAT as well as examples of National atlases (Ahmed *et al.*, 2016; Diarra *et al.*, 2019; de Gier *et al.*, 2020; Ngari *et al.*, 2020) provided the inspiration to develop a National atlas for Zimbabwe. In addition, a prospect of developing the Progressive Control Pathway (PCP) for AAT provides further justification for the development of the atlas (Diall *et al.*, 2017).

## **3.2 Materials and Methods**

### **3.2.1 Study area**

The atlas for tsetse and animal African trypanosomiasis cover a geographical area of 70 000 km<sup>2</sup>, approximately 17% of the country (Cockbill, 1975). The Division of Tsetse Control Services has a central office in Harare and nine field stations (8 for operations and 1 for research) (Map 3.1). Most tsetse infested area categorised into natural ecological region 5, where altitude is below 1000metres, the average annual rainfall is <500mm and mean temperature range is 21-25°C (Mugandani *et al.*, 2012). These climatic conditions are conducive for the survival and reproduction of *G. m. morsitans* and *G. pallidipes*.

The Division maintains a herd of cattle, sentinel herd, which was used to monitor prevalence of AAT along the tsetse belt. Wet and dry smears were collected each month from the sentinel herd cattle for microscopic examination at a laboratory in Harare.



**Map 3.1:** Tsetse Control Field stations

### 3.2.2 Input data

The Atlas initiative was launched in March 2016, and focus was placed on the systematic collation and harmonization of field data on tsetse and AAT collected from 2000. At inception, primary source of tsetse and trypanosomiasis data were monthly reports from field stations. However, during compilation of data, gaps were identified and an updated entomological data sheet was circulated all to station for fill in missing data and extract additional parameters required.

#### 3.2.2.1 Tsetse data

Entomological data sheets and internal reports containing tsetse data were captured in Microsoft Excel to create a file, which was used for the development of a tsetse atlas. Attributes on the hard copies included geo-positioning information (longitude and latitude) of the study area and traps. A Geographical Position System (GPS) was used to demarcate the geographic location where the study was carried out, and it constituted the basic unit for mapping. All sites were represented as points in the atlas of tsetse. Tsetse information incorporated in the atlas included species and sex of flies. Biting and non-biting insects caught in traps were recorded. Important elements such as dates (month and years), location (district and province), vegetation type, land use, attractants and trap code were recorded in

the atlas data table. In order for tsetse apparent densities to be calculated, the start and end date of tsetse survey period was recorded.

### **3.2.2.2 AAT data**

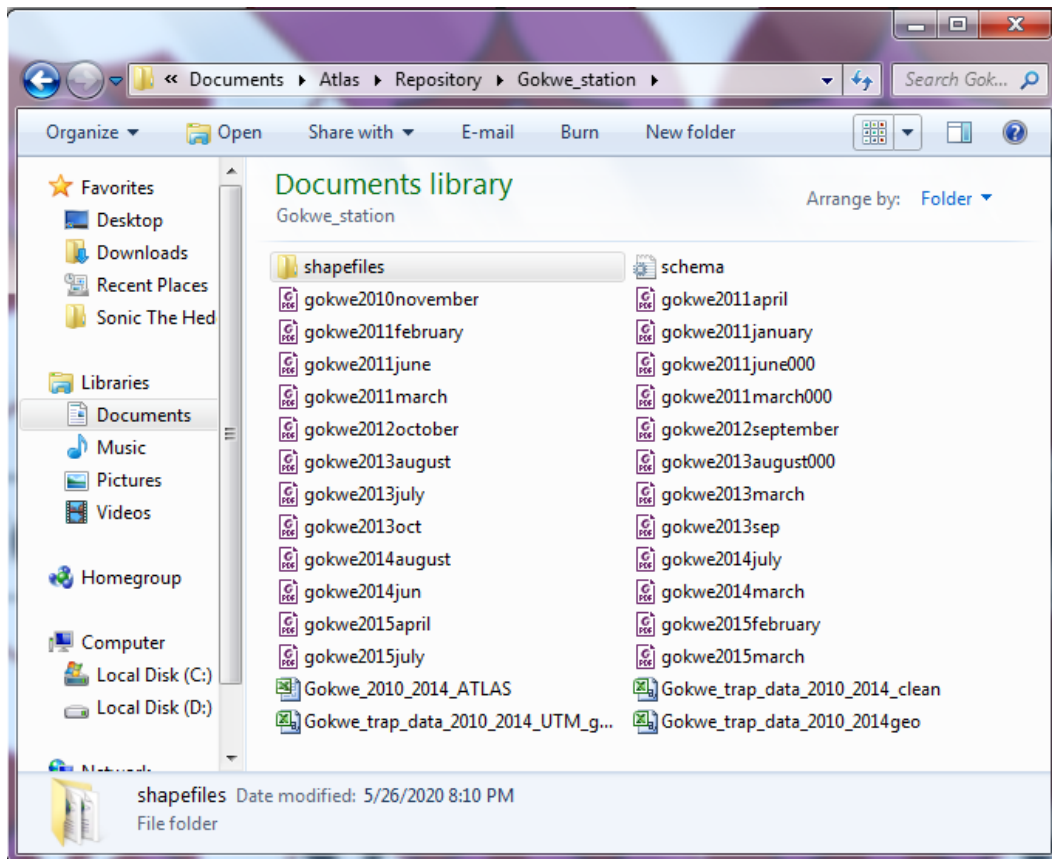
Dry blood smears were collected at diptanks and spray races in tsetse infested area for AAT parasitological monitoring by Division Veterinary Field Services (DVFS), and sent to the Tsetse Control Services laboratory for analysis. Majority of blood samples in communal herd were collected by DVFS with the sporadic sampling from Tsetse Control Services, whose mandate confines diagnosis and monitoring of AAT to sentinel herds. Occasional collections and examinations of wet smears in sentinel herd were aimed at curative drug administering to animals showing clinical signs. The trypanosomiasis atlas table contains detailed information on the geographical scope of study, it includes geo-positioning information, and it was used as a basis for mapping. All sampling sites were represented as points. Time of sample collection (day, month and year), location (diptank or spray race area, district, and province) were recorded in the atlas. Animals' information such as age, breed, sex, herd type and husbandry system were also recorded. Sampling procedures including shown in the AAT atlas. The atlas also shows trypanosomes prevalence in cattle at species level i.e *Trypanosoma congolense*, *Trypanosoma vivax*, *T. brucei* and several mixed infections, as well as management practises to control the disease. Tsetse control interventions column in the AAT atlas illustrated effort by the Division towards the elimination of AAT.

### **3.2.3 Structure of the atlas**

The atlas of tsetse and AAT for Zimbabwe comprises two major components, i.e. the data repository and the database. In order to elucidate on these components, they are given in detail in the subsequent sections.

#### **3.2.3.1 Data repository**

A digital version of all the available tsetse and AAT data from hard copy sheets was the data repository, which was used to create the database (Figure 3.1). Entomological recording sheets compiled during tsetse surveys were the original source of information used for tsetse component. For each month, original sheets were filed in the field stations, and hard copies sent to HQ for compilation and analysis. Conversion of hard copies to electronic copies was carried out at HQ.



**Figure 3.1:** An example of files in a data repository

For the AAT component, the main source of information was available in hard copy at the TCD laboratory, and it includes the results of microscopic examination of the dry thin blood smears from individual animals. In order to develop the atlas, this information was entered into spreadsheets, and aggregated by diptank and by survey period.

### 3.2.3.2 The database

The database for tsetse atlas was based on the electronic copies of all entomological sheets with aforementioned attributes such as location and survey dates. However, in the database, tsetse data was organised and computed which gave valuable information used for mapping. Epsilon traps were the only baits used for tsetse surveys. For the tsetse occurrence, data was recorded for each individual trap. Additional columns such as sum of tsetse for each species were used to calculate the apparent densities. The following mathematical formulae were used in the database;

1. GM\_TOT=Total number of *Glossina morsitans* (“MGM” + “FGM”) caught in a trap
2. GP\_TOT=Total number of *Glossina pallidipes* (“MGP” + “FGP”) caught in a trap
3. TOTAL= Total number of all flies (“GM\_TOT” + “GP\_TOT”) caught in a trap

4. AD\_GM=Apparent density of *Glossina morsitans* (“GM\_TOT” divided by “TRAP\_DAYS”)
5. AD\_GP=Apparent density of *Glossina pallidipes* (“GP\_TOT” divided by “TRAP\_DAYS”)
6. AD\_TOT=Apparent density of all flies (“TOTAL” divided by “TRAP\_DAYS”)
7. TRAP\_DAYS\_CALC= “DATE\_EN” subtract “DATE\_ST”)

Information for the AAT component includes: (i) the survey period, (ii) diagnostic method, (iii) number of animals tested, (iv) animal species and sex, and (v) husbandry system. Note was taken of the type of sampling, in particular whether it was focused on clinically suspicious animals as against random sampling, or systematic testing of an entire sentinel herd. Information on the use of trypanocidal drugs prior to the survey is also recorded. Trypanosomes were identified only to species level since the diagnostic techniques did not enable sub-species and sub-groups/types to be distinguished. Mixed infections were noted.

### **3.2.4 Mapping**

Before 2009, mapping of trap position relied on topographical maps and traditional cartographic techniques. Thereafter, the Geographic Positioning System (GPS) has replaced traditional cartography. The geo-referencing of the tsetse data is at the level of individual traps. In the GIS, shape files of the province, district, field station and location were loaded whilst traps, spray race or diptank were inputted as points. Presence/absence maps for tsetse and AAT were produced in Quantum and Arc GIS from geographical coordinates recorded as latitude and longitude on the WGS84 datum. Apparent densities and prevalence maps were also produced respectively for tsetse and AAT. Data on the AAT component of the atlas were mapped at the level of the diptank or spray race where samples were collected, or the site where the sentinel herds was located.

### **3.2.5 Atlas development process**

During the initial data compilation for atlas development, some periods had missing information as several hard copies of field operations results were destroyed by fire at HQ. In order to fill the data gaps, standardised templates for tsetse and AAT data were sent out to all field stations. All the retrieved information for the study period were relayed to HQ in either hard copy or electronic form. Thereafter, data harmonisation was carried out, for example to ensure consistency in the format of geographic coordinates and dates. Data integrity through verification and quality control to remove data entry errors was carried out.

### **3.2.6 Trap collectors and trap covers on tsetse catches**

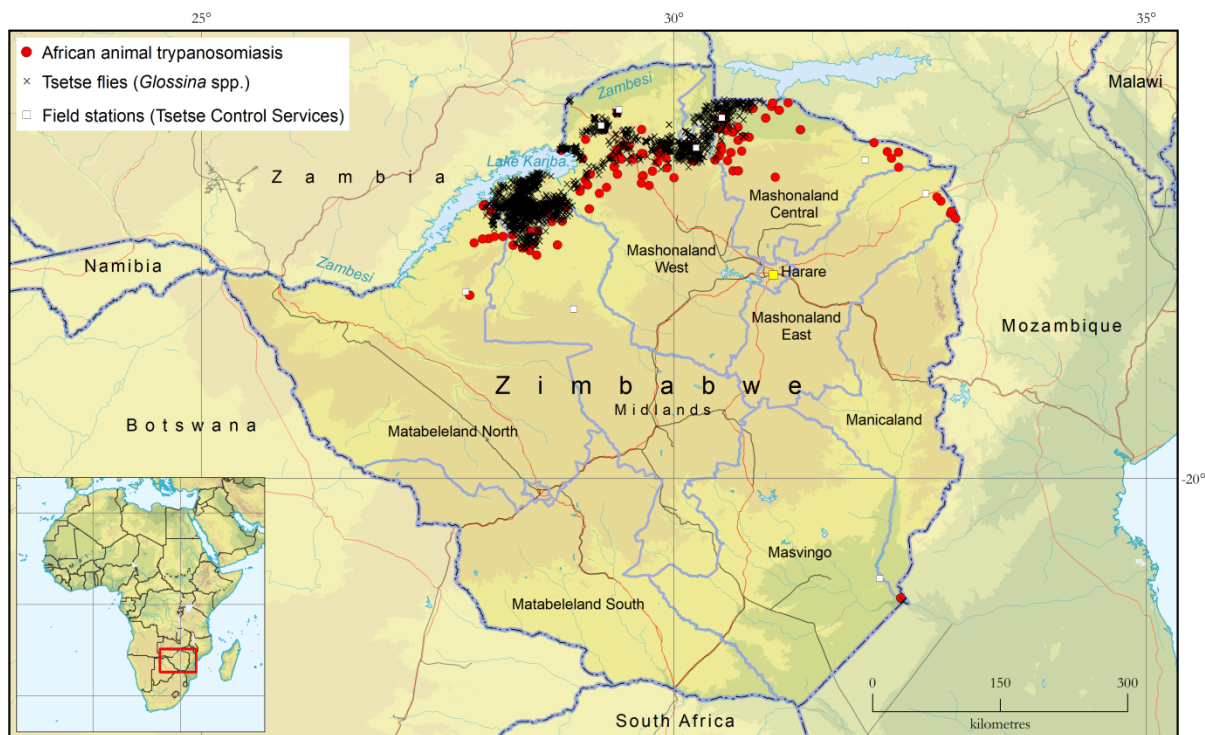
Traps were set up in areas known to be tsetse infested at Rekometjie research station to assess the impacts of collectors and trap cloth on tsetse catches. For both aspects, a 3x3 latin square design was used. For trap cloth material, three treatments were assessed (Cotton drill, new Vestergaard trap and faded Vestergaard trap) and for the collectors, treatments evaluated were plastic bottle, plastic bottle with plastic collector and steel cage with netting. Treatments were rotated every day to ensure they all experience equal number of days in any of the sites. The experiments ran for 33 days hence there were 11 replicates for each site.

## **3.3 Results**

### **3.3.1 Tsetse and AAT atlases**

An average trap monitoring interval of 166 days, a minimum of 2 days to a maximum of 3 921 days, was recorded in 4894 distinct trapping sites present in the tsetse atlas. A total of 33 872 entomological records/trapping events were included in the database. Over 99% of the entomological records include geographic coordinates. All records include the month and year of trapping, and approximately 51% also include the exact days of deployment and monitoring. The exact trapping durations i.e. start and end dates, are available for 21 180 records (63%), which were used to calculate apparent densities [flies/trap/day]. For the 63% of records that include information on the duration of trapping, the cumulative trapping intensity is in excess of 570 000 trap days, equating to an estimated overall trapping intensity close to 1 million trap days, if records without trapping durations are included.

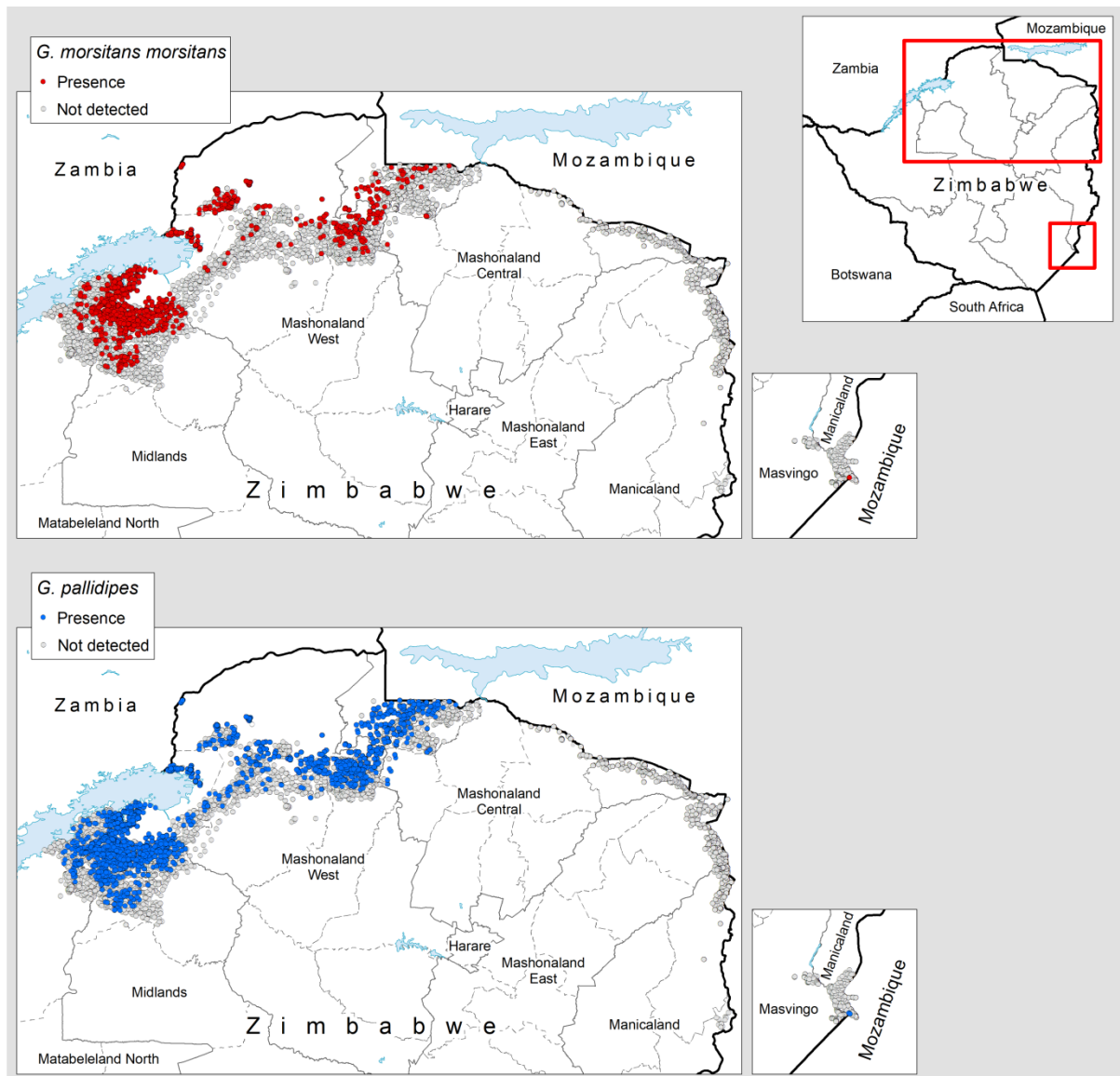
The AAT component of the atlas comprises 4 178 parasitological records collected from 280 sites. The overall sampling intensity was 82 080 animals, with the detection 1260 *T. brucei* infections, 574 *T. congolense*, and 207 *T. vivax*. The reported geographic distribution of AAT at the national level is shown in Map 3.2



**Map 3.2:** Occurrence of tsetse and animal African trypanosomiasis in Zimbabwe: 2000–2019

### 3.3.2 Tsetse Distribution

The total number of tsetse caught in the study was 995 749, comprising 823 807 *G. pallidipes* and 171 942 *G. m. morsitans*. The presence/absence of capture by species is shown in Map 3.3. No *G. brevipalpis* and *G. austeni* were reported, although these species were occasionally reported until the 1990s along the border with Mozambique (Thakersi, 1992).



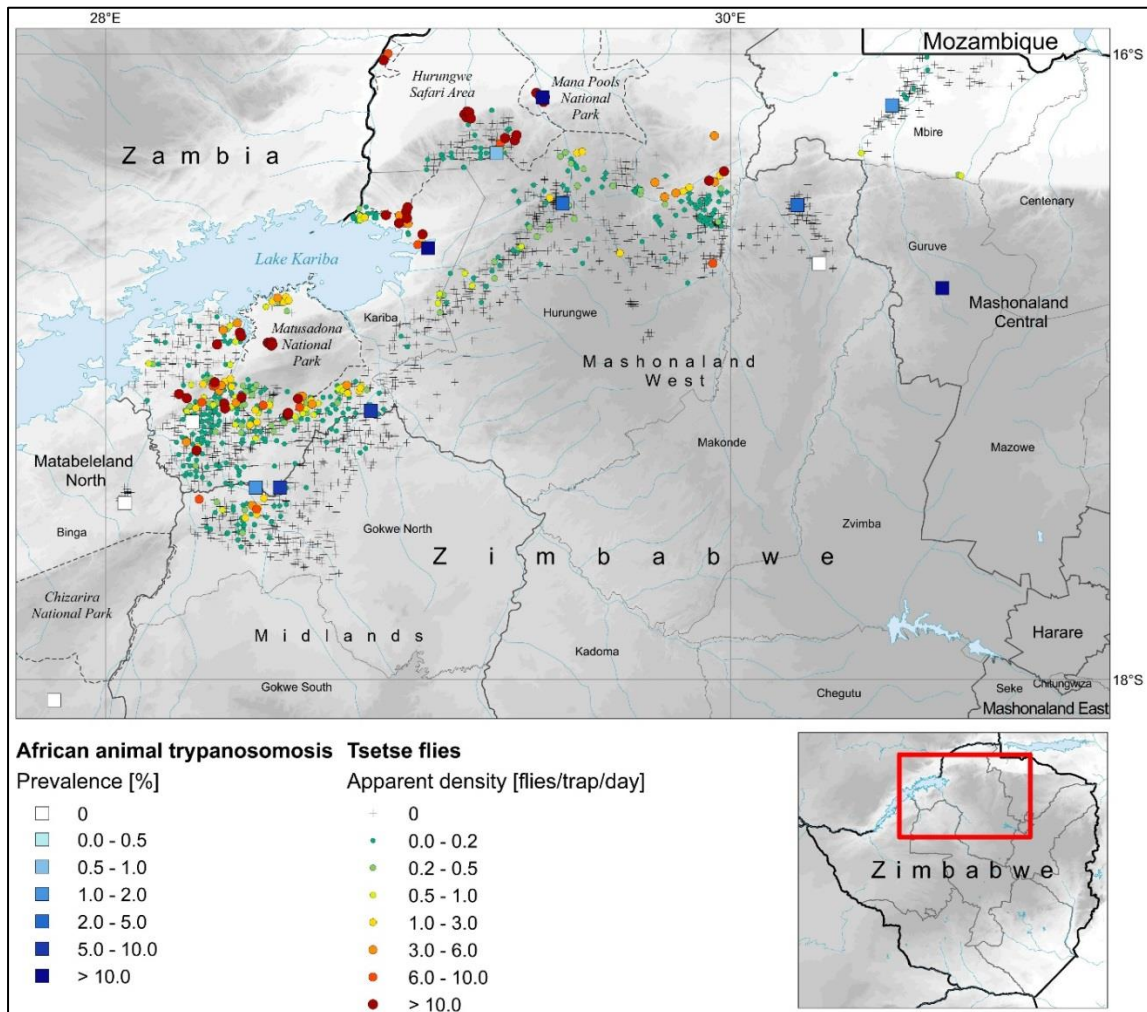
**Map 3.3:** Presence (coloured circle) and absence (surveyed but not detected, grey circles) of *G. m. morsitans* and *G. pallidipes* in Zimbabwe: 2000-2019

Tsetse are confirmed to be present in the N and NW parts of the country. By contrast, substantial trapping efforts in the NE along the border with Mozambique resulted in no catches. Limited monitoring in the SE detected flies in only one location, where the last tsetse was caught in 2005.

### 3.3.3 Tsetse Apparent densities

The data assembled in the atlas will open the door to a range of analyses and modelling exercises (Bouyer *et al.*, 2015; Dicko *et al.*, 2015). For example, in addition to the presence and absence maps presented in the results section, the atlas also allowed for tsetse apparent

density and AAT prevalence maps to be generated e.g. Map 3.4. The mean apparent densities for *G. m. morsitans* and *G. pallidipes* were 0.13 and 0.91 flies/trap/day respectively, for the entire survey period.



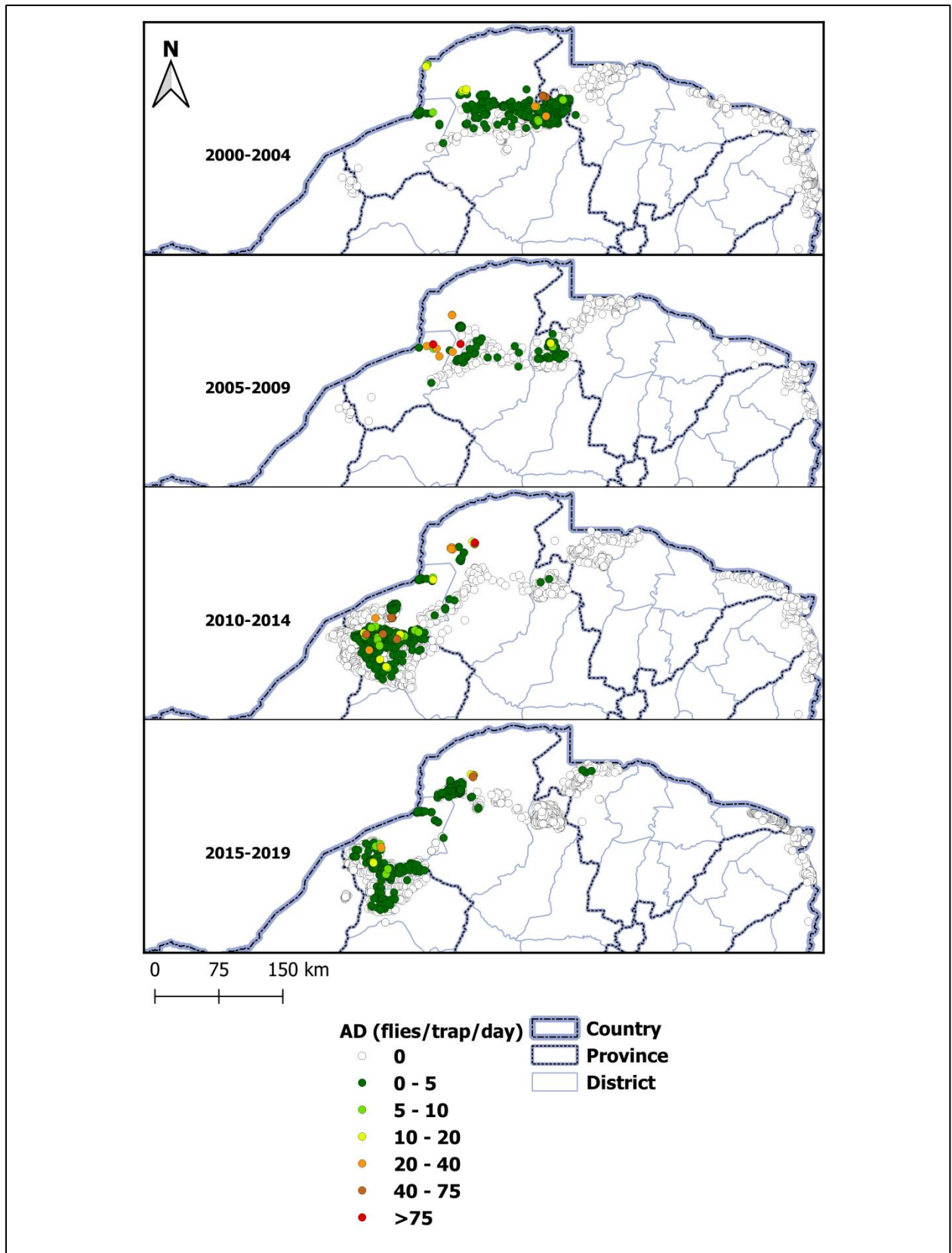
**Map 3.4:** Example of map of tsetse apparent density (flies/trap/day) and animal African trypanosomiasis prevalence (%).

However, care will be needed when analysing such a dataset. For example, one cause of bias that could affect future analyses is related to the fact that, in certain areas and for certain periods, results of entomological surveys were only reported from traps that captured tsetse flies, while zero catches were not reported. Also, calculation of apparent densities is hindered for some records by the lack of start and end dates of trapping (and the related duration of trapping), a problem that is more common for the first, earlier half of the study period (2000-2009). Due to changes in the source companies, trap cloth materials varied in colour and texture over time. Duration of the traps in the field was not always consistent, with some traps being monitored daily or every 3 days while others were monitored once every month

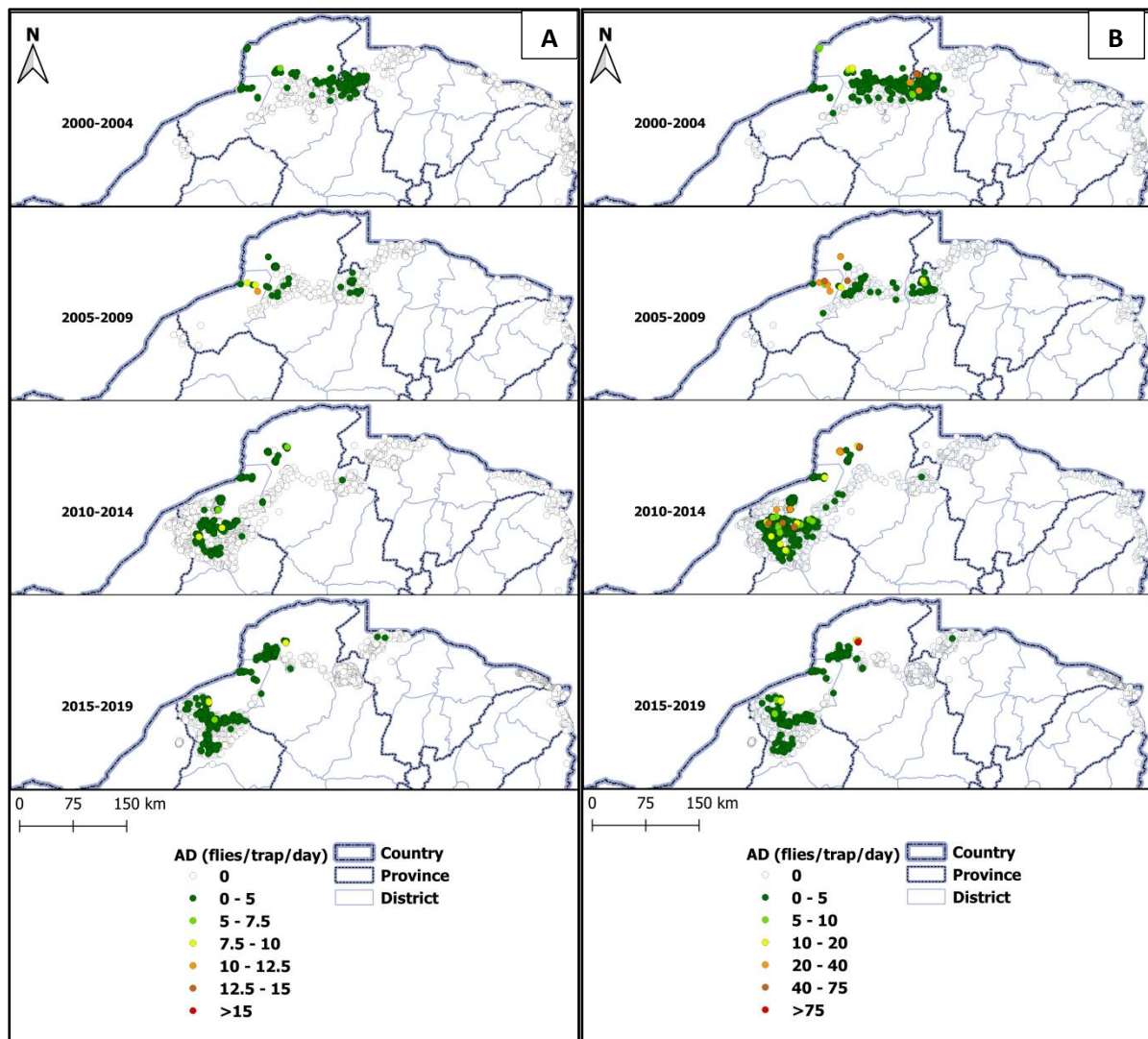
or after a period longer than a month. Traps that were kept for longer periods in the field became faded due to the effect of sun light. The impacts of these changes on trap efficiency were compared under field conditions. Results from these studies will be crucial as the analysis of data will take into consideration variations in the trap material, cages and odour attractants. Wherever necessary, data was adjusted using appropriate correction factors to compare trap catch efficiencies and apparent densities.

#### **3.3.3.1 Time series change in apparent densities**

The atlas has been essential in assisting to visually note the changes which occurred over time in terms of tsetse apparent densities as shown in Map 3.5. Pooled catches for *G.m.morsitans* and *G.pallidipes* are shown in blocks of five years from 2000 to 2019. The same was also done to assess changes in apparent densities for each of the two species as indicated in Map 3.6.



**Map 3.5:** Pooled *G. m. morsitans* and *G. pallidipes* apparent densities in Zimbabwe: 2000-2019



**Map 3.6:** *G. m. morsitans* (A) and *G. pallidipes* (B) apparent densities in Zimbabwe: 2000-2019

Results clearly indicate that sampling intensity was low between 2000 and 2009, and from 2010-2019 it increased. The trend is applicable to both species under investigation. It is also essential to highlight the difference in apparent densities where it is evident that *G.pallidipes* densities were higher than *G.m. morsitans*.

### 3.3.3.2 A comparative study of different trap collectors, trap covers and odour attractants

#### Trap cloth material

Mean tsetse catches were highest for Cotton drill followed by faded polyester cotton (Vestergaard) cloth and least catches were in new polyester cotton (Vestergaard) trap.

Statistical analysis, analysis of variance (ANOVA) conducted on data collected in the experiment indicated that there was a significant difference between treatments. Post hoc analysis for mean separation revealed that only female *G. pallidipes* catches using Cotton drill were significantly different from catches in both Vestergaard treatments. However, there was no significant difference between faded and new Vestergaard cloth material on female *G. pallidipes* catches. Table 3.1 shows the detailed results for the analysis conducted. There was however no statistically significant difference between catches for male and female *G.m.morsitans* and male *G. pallidipes*.

**Table 3.1:** Mean tsetse catches using different cloth materials

Treatment	<i>Glossina. m. morsitans</i>		<i>Glossina pallidipes</i>	
	Males	Females	Males	Females
Cotton <b>drill + odour</b>	0.0606061 (0.0182442) <sup>a</sup>	0.2121212 (0.0562828) <sup>a</sup>	4.7878787 (0.6612516) <sup>a</sup>	16.818181 (1.1141265) <sup>a</sup>
Polyester Cotton (33/67%) (Vestergaard) <b>faded + odour</b>	0.0303030 (0.0091221) <sup>a</sup>	0.03030303 (0.0091221) <sup>a</sup>	4.7272727 (0.5941662) <sup>a</sup>	10.727272 (0.8862705) <sup>b</sup>
Polyester Cotton (33/67%) (Vestergaard) <b>new + odour</b>	0.1212121 (0.0364884) <sup>a</sup>	0.0606060 (0.014458) <sup>a</sup>	3.3030303 (0.485293) <sup>a</sup>	8.7575757 (0.8130654) <sup>bc</sup>

Logarithmic [Log (n+1)] transformed means shown in parentheses; statistically significant means in each column are denoted with different letters <sup>a,b or c...</sup> at P < 0.05 (ANOVA)

### Trap collectors

Mean tsetse catches were highest for plastic bottle with plastic bag collector closely followed by plastic bottle and least was the steel cage with netting. Statistical analysis, analysis of variance (ANOVA) conducted on the data showed no significant difference between treatments at 95% confidence interval as shown in Table 3.2.

**Table 3.2:** Mean tsetse catches using different tsetse collectors

Treatment	<i>Glossina. m. morsitans</i>		<i>Glossina pallidipes</i>	
	Males	Females	Males	Females
plastic bottle	0.363637000 (0.134698777)	0.454547000 (0.162727759)	4.909087000 (0.771520384)	12.727273000 (1.137584271)
plastic bottle with plastic collector	0.636365000 (0.213880182)	0.999995000 (0.30102891)	4.909089000 (0.771520531)	18.181814000 (1.282889675)
steel cage with netting	0.090909000 (0.037788525)	0.090909000 (0.037788525)	3.454546000 (0.648803448)	10.272727000 (1.052028989)

Logarithmic [Log (n+1)] transformed means shown in parentheses

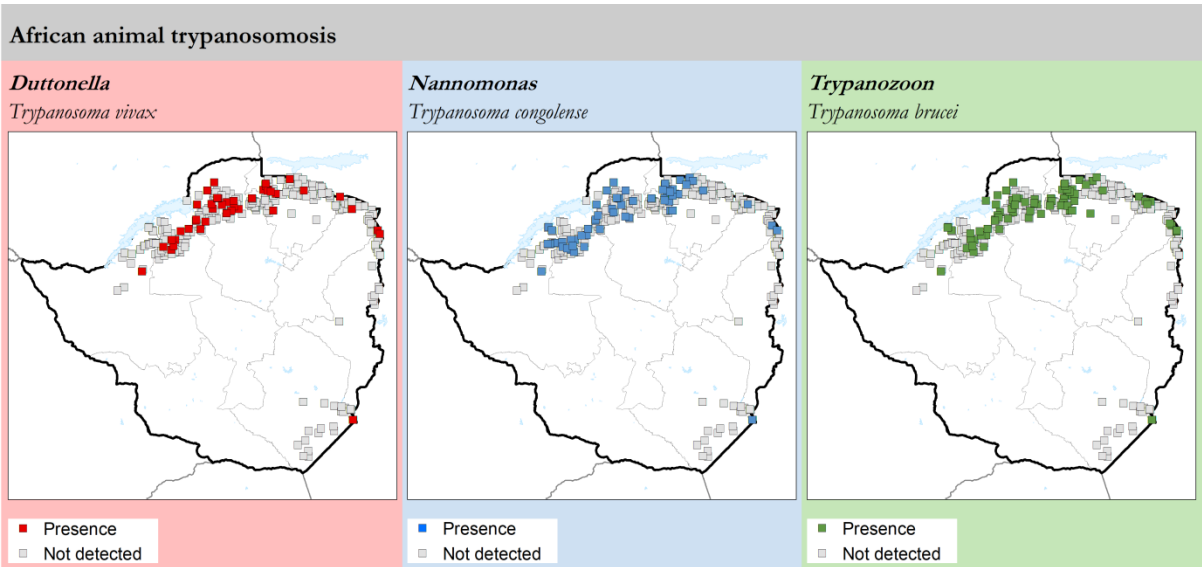
### Correction factors for odour attractants

In most cases a full complement of odours was used while in a few instances methyl-ethyl ketone (MEK) or acetone was missing. In such instances, correction factors were used to adjust the fly catches in the calculation of apparent densities and for other statistical analyses.

### 3.3.4 Animal African trypanosomiasis distribution

The distribution of AAT in Zimbabwe appears to be closely related to tsetse distribution, in particular in the tsetse-affected areas in the N and NW (Map 3.2). The sporadic positive cases of AAT detected in the NE, along border with Mozambique, seem to be imported infections, since follow-up investigations by DVFS and TCD revealed transboundary animal movement and yielded no new AAT cases or tsetse catches. In the SE of the country, AAT cases were detected in a sentinel herd, the last case having been reported in 2005.

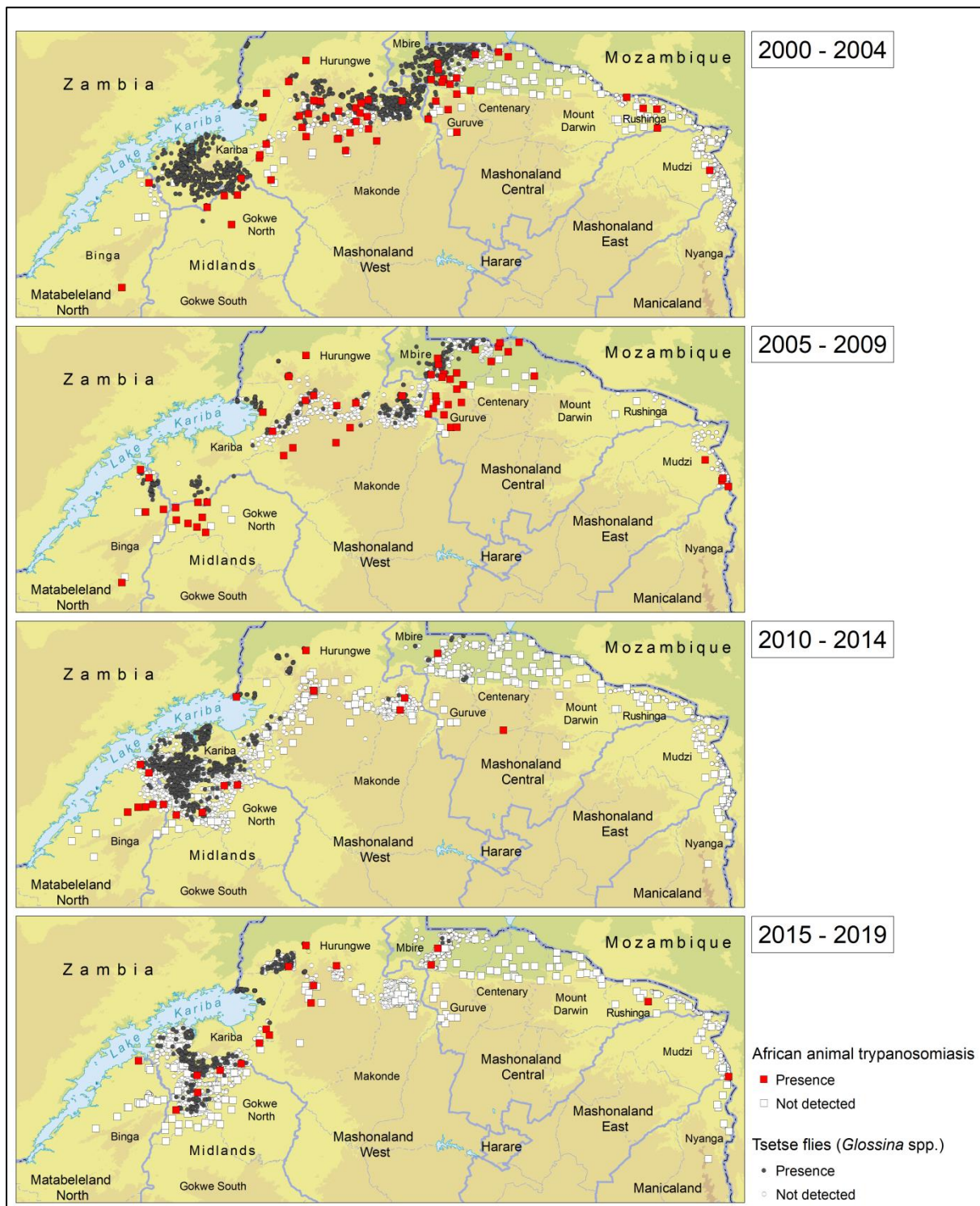
Trypanosome prevalences in sentinel herds were 2.22%, 0.43% and 0.30% for *T. brucei*, *T. congolense* and *T. vivax* respectively. Despite these differences in prevalence, no major difference in the geographic distribution of trypanosome species is apparent.



**Map 3.7:** Presence (coloured circles) or absence (surveyed but not detected, grey circles) of *T. vivax*, *T. congolense* and *T. brucei* in blood smears collected in Zimbabwe in 2000-2019.

Atlas results for tsetse and AAT occurrence in Zimbabwe from 2000 to 2019 are shown on Map 3.2 while the maps of presence and absence by trypanosome species are shown in Map 3.7.

### 3.3.5 Time series changes in the distribution of tsetse and trypanosomiasis



**Map 3.8:** Spatio-temporal changes in tsetse and AAT distribution: 2000-2019

Map 3.8 shows in four time windows changes in tsetse and AAT distribution in northern Zimbabwe during the 20-year study period. Despite an uneven coverage of surveillance activities, a few major patterns can be observed. In particular, a reduction in tsetse

distribution and a decline in AAT occurrence was observed. The decline of tsetse populations is particularly evident in the central part of northern Zimbabwe (i.e. Mbire district and northern part of Makonde district), but also visible to a lesser extent in areas to the West (i.e. Hurungwe and Kariba districts). In the eastern part, no fly was captured during the whole study period, although a reduction in the geographical coverage of surveillance is visible. Similar, albeit less stark, patterns can be observed for the occurrence of AAT in space and time.

### **3.4 Discussion**

The goal of assembling, harmonizing and geo-referencing tsetse and AAT data collected by the TCD and DVFS for the period 2000-2019 has been achieved. This national atlas for Zimbabwe follows the ones for Sudan (Ahmed *et al.*, 2016), Mali (Diarra *et al.*, 2019) and Kenya (Ngari *et al.*, 2020), but vastly exceeds them in respect of the number of data points. In particular, the overall trapping effort in Zimbabwe is approximately 1 million trap days, compared to less than 20,000 trap days in Mali and Kenya.

The atlas enabled TCD to delineate vector and disease occurrence and distribution in Zimbabwe. However, one of the weakness in the atlas is that no flyround tsetse survey data were compiled as *G. m. morsitans* are known to be more attracted to mobile baits (Vale, 1974; Leak, Ejigu and Vreysen, 2008). Existence of gaps in both the tsetse and AAT data sets limit the understanding of vector and disease distribution. These gaps are not attributed to the present data collation, harmonisation and geo-referencing but to a lack of information.

The atlas shows that tsetse and AAT in Zimbabwe occur in the N and NW. The absence of flies in the NE, an area well covered by the atlas, is mainly explained by extensive tsetse control interventions implemented before 2000, involving ITT, ITC, ground spraying and sequential aerial spraying, but also to the sustained use of ITT and ITC as the methods of choice in the following two decades.

In order to address the lack of standard procedures in the trapping system, for example, variations in the odours employed, the sorts of collector (cage) used to catch flies in traps, the types of cloth used for trap manufacture, and the frequency of monitoring visits to traps, investigations conducted to assess the effects of these variations. The investigations were conducted with the view to correct the observed catches to what they would have been if the

trapping procedure and trap construction had been standardised. Trap collectors had no effect on tsetse catches hence were not corrected.

The present atlas enables gaps in the geographic coverage of surveillance to be identified. Hardly any recent information is available for the vast areas of the country that are assumed to be free of tsetse and AAT. Also, data are lacking from parts of the Mana Pools National Park in the Zambezi valley, where tsetse are known to be present.

The geographical coverage of the AAT component is adequate for decision-making. However, in the context of the progressive control pathway (PCP) for AAT and the related OIE criteria for declaring freedom from disease, it will be necessary to produce data to confirm the presumed AAT-free status of many areas. The fact that the AAT distribution appears to follow closely the tsetse distribution seems to indicate that, in Zimbabwe, the capacity of mechanical vectors and animal movement to cause disease in tsetse-free areas is very limited. At the same time, the transboundary nature of the disease is apparent in the NE where, due to cross border animal movement, sporadic AAT cases were detected in an area that is believed to be free of tsetse.

AAT survey results in the atlas (Map 3.8) are similar to those presented by Torr, 1997, as both were based on microscopic examination of samples. Overall, more cases were detected in the survey by Van den Bossche, which spanned from January 1998 to September 1999 (Van den Bossche and Vale, 1999), as both microscopy and the Enzyme-Linked Immunosorbent Assay (ELISA) were used. Parasitological surveys gave comparable results except in the Northern region where more cases were detected. The reduction of cases in the North could be attributed to the increased resettlement of people and the related extensive deforestation for agricultural activities and for curing tobacco. Further, the differences could also be due to reduced tsetse invasion and cattle dipping in the NE and SE, target operations, ground spraying and cattle dipping in the NW and target operations and cattle dipping in the North. In most areas surveyed, the true AAT prevalence situation was distorted by the increased informal and unreported usage of curative drugs by farmers, a situation that reduces parasitemia levels and therefore chances of detecting the disease by microscopy.

One of the main weaknesses in the collection of the AAT data for the atlas was the non-randomisation of sampling at dip tanks and spray races, which limits the ability to estimate

disease prevalence. Another weakness is related to the generally low sensitivity of the blood-smear method of diagnosis. Furthermore, reduced parasitemia, due to undeclared treatment of cattle with trypanocidal drugs by farmers, can reduce the chances of detection of trypanosomal infections using the traditional microscopy. Recently, the sensitivity of the AAT diagnostic protocols was improved by establishing a Polymerase Chain Reaction (PCR) unit to enable identification to sub-species and subgroup level. Data originating from molecular analysis will be included in future versions of the atlas.

The data assembled in the atlas will be useful for a range of analyses and modelling (Bouyer *et al.*, 2015; Dicko *et al.*, 2015), for example, to model effects of climate, human settlement and control interventions on tsetse, and to develop the PCP for AAT.

### **3.5 Conclusion**

The national atlas of tsetse and AAT represents a key tool for data management and can be used to inform tactical and strategic decision-making in tsetse and AAT control. Establishing an atlas has enabled existing data collection and reporting procedures to be refined, and their accuracy and robustness enhanced. The atlas is useful in delineating areas currently infested with tsetse and in monitoring changes in tsetse distribution, thereby providing a basis for identifying priority areas for control interventions.

### **3.6 Recommendation**

The atlas of tsetse and AAT needs to be regularly updated as well as filling up geographic gaps by conducting tsetse surveys and trypanosomiasis surveillance in areas where data does not exist. To the extent possible, it will be expanded to include older datasets i.e. before the year 2000. Data collected for research and published in the scientific literature also needs to be systematically included. There is need to consider migration of the Excel spreadsheet form of database to more robust databases like Microsoft access. The atlas is a tool that should be used to inform planning, decision-making and policy on tsetse and AAT control in the country. In this context, the country is developing its PCP and PCP-smart strategies towards the elimination of AAT.

### **Progressive Control Pathway for AAT**

This is a stepwise approach for the reduction, elimination and eradication of AAT (Diall *et al.*, 2017) that was developed by the FAO in collaboration with the IAEA, AU-PATTEC and

CIRAD. This risk based targeting of interventions is considered crucial for cost-effective disease control (de Gier *et al.*, 2020).

In developing the PCP, the country has produced a PCP self-assessment of the capacity to control AAT, categorised the country into various stages of the PCP and formulated a roadmap towards the elimination of AAT for the next 5 years.

The PCP for AAT comprises five levels (stages 1-5) and a pre-entry level named ‘below Stage 1’. At below stage 1, Political and financial commitment of a country is a key requirement for entry into the PCP. The self-assessment analyzes a country’s epidemiological knowledge of the disease, its institutional arrangements, which should include a Specialized National Structure (SNS) for the control of AAT. Stage 1 is the stage for capacity development, risk assessment and selection of priority areas for intervention (Cecchi *et al.*, 2013; Ahmed *et al.*, 2016). Establishment of a national-level information system / national atlas (Cecchi *et al.*, 2013; de Gier *et al.*, 2020; Ngari *et al.*, 2020) is another requirement for Stage 1. Stage 2 is the stage of implementing AAT control programmes to achieve sustainable reduction of AAT risk. Effective strategies including use of tsetse control methods and trypanocidal drugs will be used. Parasitological, entomological, and socio-economic data are collected in the control zone to measure progress and impact. Stage 3 focuses on the interruption of AAT transmission and not necessarily on the elimination of the tsetse vector. Emphasis is therefore placed on the intensification of tsetse control interventions to break transmission. Stage 4 is when AAT transmission has been eliminated, when there is no tsetse and no parasite. However, some level of control has been maintained. Stage 5 is the final stage when there is no tsetse and no parasite. All control measures have been lifted.

### **PCP self-assessment of the capacity of Zimbabwe to control AAT**

#### *National Commitment*

In Zimbabwe, there is a strong government commitment towards the control of tsetse and trypanosomiasis (T&T) as demonstrated by the establishment of a specialised structure and the allocation of funding for T&T control programmes.

### *Epidemiological knowledge of the disease*

Zimbabwe has an intricate network of diptanks where cattle are brought in for animal disease inspection and for weekly or fortnightly dipping against ticks and, where applicable, against ticks and tsetse. Through this network, treatments with trypanocidal drugs are administered by the Division of Veterinary Field Services (DVFS). In Zimbabwe, the main compounds used for treatment are, Isometamidium chloride (commonly known as samorin) and Diminazene aceturate (berenil).

### *Institutional Arrangements*

TCD is one of the Divisions within the Department of Veterinary Services and is coordinated from the Head Office in Harare. There are 8 operational field stations and 1 research station in the Zambezi Valley. The country has a specialised structure dedicated to the implementation of tsetse control programmes. The Division works closely with the Veterinary Field Services whose role is to control animal diseases control, diagnostics and vaccine development. TCD is also assisted in carrying out its mandate by the Private Sector and Farmer organizations, Non-Governmental Organizations and International Organizations such as FAO, OIE, IAEA, WHO, SADC, and PATTEC

### *Human resources*

The Division has a staff establishment of 525 consisting of 1 Director, 1 Deputy Director, 3 Chief Glossinologists, 12 Glossinologists, 10 Chief Tsetse field officers, 30 Tsetse field officers, 157 Tsetse field Assistants and 311 General staff.

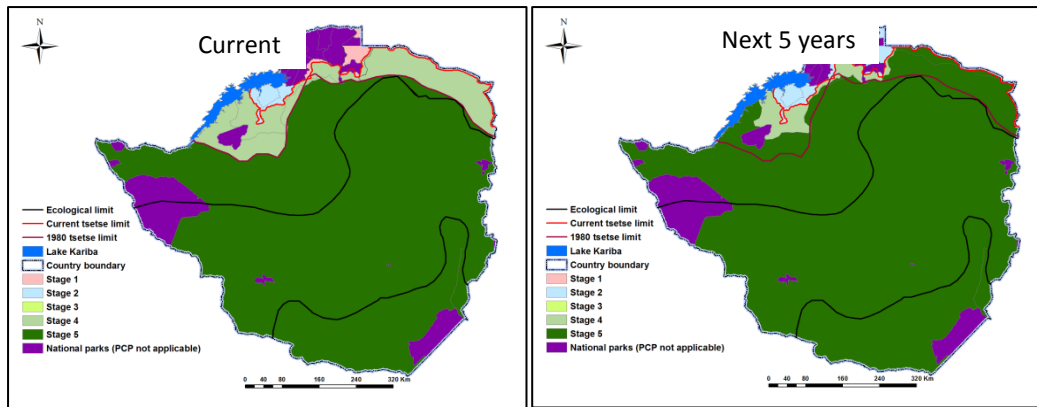
### *Financial resources*

Government allocated funds for tsetse control for 5 years as follows:

**2017: US\$3 677 525, 2018: US\$4 263 000, 2019: US\$6 432 000, 2020: US\$3 677 525, 2021: US\$ 10 045 000**

### **Categorization of AAT zones into PCP stages, in Zimbabwe**

AAT zones were categorized into the various PCP stages based on the national atlas for tsetse and AAT for Zimbabwe. AAT atlas data for the last 1-3 years and recent control measures were taken into consideration in assigning PCP status to a zone.



**Map 3.9:** Current (left) and Future (right) PCP stages of AAT control

Some additional random surveys for AAT prevalence with more sensitive diagnostic tools might be necessary to give more confidence on the disease freedom status of certain areas.

The PCP is an important tool that will be used to develop the next 5-year national strategy. The tool is a valuable in that can be used to develop a year by year plan on how to tackle AAT challenge and also determine techniques to adopt in the process. The self-assessment gave detailed information on the TCD's standing in terms of resources by highlighting what is available and the existing gaps. In terms of declaration of AAT freedom status, the PCP is in compliance to the OIE standards as outlined in the OIE terrestrial animal health code chapter on tsetse-transmitted trypanosomiasis.

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### Box 1. University Degrees conferred from field work conducted at Rekomitjie

#### *Doctoral theses*

1. **Vale, G.A.** (1973) *Responses of tsetse flies (Diptera: Glossinidae) to mobile and stationary baits*. University of London. 160 pp.
2. **Hargrove** (1973) *The physiology of flight in tsetse*. University of London. 289 pp.
3. **Taylor, P.A.** (1974) *Energy balance in tsetse*. University of London
4. **Mackenzie, P.K.I.** (1976) *Trypanosomiasis in sheep due to Trypanosoma (Nannomonas) congolense*. Volumes 1 and 2. PhD thesis, University of Birmingham. (Through the University of Rhodesia). Vol. 1, 258 pages. Vol. 2, 122 pp.
5. **Torr, S.J.** (1988) *The host-orientated behaviour of tsetse flies (Diptera: Glossinidae)*. University of London. 210 pp.
6. **Groenendijk, C.A.** (1996) *The behaviour of tsetse flies in an odour plume*. Ph.D thesis. University of Wageningen, The Netherlands. 162 pp.

#### *Masters theses*

1. **Thomson, M.** (1987) *The effect on tsetse flies (Glossina spp.) of deltamethrin applied to cattle either as a spray or incorporated into ear-tags*. MSc (Applied Entomology), University of London. c. 100 pp.
2. **Manokore, V.** (1993) *Efficacy of some synthetic pyrethroids on net plus cloth targets used for tsetse fly (Diptera : Glossinidae) control*. MSc (Tropical Entomology), University of Zimbabwe. 91 pp.
3. **Mhindurwa, A.** (1998) *The detection of traces of deltamethrin contamination to the environment through wash-off water from target cloths used in tsetse control operations during the rainy season*. MSc (Tropical Entomology), University of Zimbabwe
4. **Mireji, O.P.** (2000) *Effects of oils on Glossina pallidipes (Austeni) and G. morsitans morsitans (Westwood) behaviour and on deltamethrin toxicity and persistence*. MSc (Tropical Entomology), University of Zimbabwe
5. **Tsikire, D.** (2016) *Age-specific trypanosome infection rates in G.m.morsitans and G. pallidipes as a function of season and climate*. MSc (Tropical Entomology), University of Zimbabwe

#### *Final year Bachelor degree theses*

1. Abson, J. BSc degree (1992), Rhodes University, Grahamstown.
2. Loveridge, A. BSc degree (1993), Rhodes University, Grahamstown.
3. Wilcox, J. BSc (Honours) degree (1991), University of Southampton.

**Box 2. Academic and Professional Awards from tsetse research at Rekomitjie**

***Academic and Professional Awards***

**G. A. Vale.**

Gold Medal of the Zimbabwe Scientific Association.	1976
Special Award of the Natural Resources Board, Zimbabwe.	1979
Certificate of Distinction, awarded by the Prime Minister of Zimbabwe.	1985
Ciba-Geigy International Prize for Research in Animal Health.	1987
Verrall Tankard of the Royal Entomological Society, for delivering the first Verrall lecture.	2000
Gold Medal of the Organisation of African Unity, on the occasion of the 50 <sup>th</sup> Anniversary of the International Scientific Council for Trypanosomiasis Research and Control.	2001
Honorary fellow of the Royal Entomological Society.	2003
Fellow of the World Technology Network.	2008
Awarded OBE in the Queen's Birthday Honours list "for services to controlling and eradicating tsetse flies in Africa".	

**J. W. Hargrove**

Silver Medal of the Organisation of African Unity, on the occasion of the 50 <sup>th</sup> Anniversary of the International Scientific Council for Trypanosomiasis Research and Control.	2001
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**S.J. Torr**

Thomas Henry Huxley Award by the Zoological Society of London.	1988
Ph.D. for the doctoral thesis "The host-orientated behaviour of tsetse flies (Diptera: Glossinidae)".	

Certificate from the Royal Entomological Society for best paper published in  
Medical & Veterinary Entomology 2001-2002. (For: Torr, S.J., Wilson, P.J.,  
Schofield, S., Mangwiro, T.N.C., Akber, S. & White, B.N. (2001). Medical and  
Veterinary Entomology, 15, 78-86)

Certificate from the Royal Entomological Society for best paper published  
in Medical & Veterinary Entomology 2007-2008. (For: Torr, S.J., Della Torre, A.,  
Calzetta, M., Costantini, C. & Vale, G.A. (2008) Medical and Veterinary  
Entomology 22, 93-108).

Finalist for the 2007 Times Higher Awards 'Project of the Year'

<https://www.nri.org/latest/news/2007/tsetse-project-short-listed> –for times higher award

## Research Ethics Approval



UNIVERSITEIT VAN PRETORIA  
UNIVERSITY OF PRETORIA  
YUNIBESITHI YA PRETORIA

Faculty of Veterinary Science

Research Ethics Committee

16 March 2020

### LETTER OF APPROVAL

Ethics Reference No	REC259-19
Protocol Title	DYNAMICS OF TSETSE AND TRYPANOSOMIASIS: HISTORICAL IMPACTS OF TSETSE CONTROL: A CASE OF ZIMBABWE
Principal Investigator	Mr W Shereni
Supervisors	Prof LCBGD Neves

Dear Mr W Shereni,

We are pleased to inform you that your submission conforms to the requirements of the Faculty of Veterinary Sciences Research Ethics committee.

Please note the following about your ethics approval:

1. Please use your reference number (REC259-19) on any documents or correspondence with the Research Ethics Committee regarding your research.
2. Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, monitor the conduct of your research, or suspend or withdraw ethics approval.
3. Please note that ethical approval is granted for the duration of the research as stipulated in the original application (for Post graduate studies e.g. Honours studies: 1 year, Masters studies: two years, and PhD studies: three years) and should be extended when the approval period lapses.
4. The digital archiving of data is a requirement of the University of Pretoria. The data should be accessible in the event of an enquiry or further analysis of the data.

Ethics approval is subject to the following:

1. The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.
2. **Applications using Animals: FVS ethics recommendation does not imply that AEC approval is granted. The application has been pre-screened and recommended for review by the AEC. Research may not proceed until AEC approval is granted.**

Recommend approval

We wish you the best with your research.

Yours sincerely

PROF M. OOSTHUIZEN  
Chairperson: Research Ethics Committee

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**100**  
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Lefapha la Disaense tša Bongakadiruwa