A Brief History of Tsetse Control Methods in Zimbabwe and Possible Effects of Climate Change on Their Distribution

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Abstract

African trypanosomiasis, which affects wildlife, domesticated animals and humans, remains widespread across Africa. Approximately 8 million km^2, covering 37 African counties, are infested with tsetse flies (*Glossina*) that carry the disease (Allsopp 2001). The first part of this paper looks at the history of tsetse control on the northern fly-belt in Zimbabwe, affecting the Mashonaland East, Mashonaland Central and Mashonaland West provinces. In Zimbabwe, tsetse control has shifted and evolved in the twentieth century, ranging from the initial methods of game destruction and bush-clearing, to ground and aerial spraying of insecticides, the sterile insect technique (SIT), tsetse trapping, and the use of insecticides applied to cattle or to artificial baits called targets. The second part of the paper looks at the possible effect of climate change on the abundance and distribution of tsetse by considering how changes in temperature could affect life cycles and breeding patterns. The analysis offers suggestions for the means of alleviating the future effects of any alteration in human-tsetse contact resulting from changes in climate, land use and human populations.

Introduction

African trypanosomiasis, which affects wildlife, domesticated animals and humans, remains widespread across Africa. Approximately 8 million km^2, covering 37 African counties, are infested with tsetse flies (*Glossina*) that carry the disease (Allsopp, 2001). The World Health Organisation (WHO) estimates that up to 70 million people, as well as 50 million cattle, currently live with the risk of exposure (WHO, 2010). The potential economic loss from the disease amounts to US$4.75 billion a year, indicating the developmental benefits from controlling the disease and the vectors (Scoones, 2014). In reaction to these figures, WHO initiated new control and surveillance programs. From 2000 to 2009, 30 countries received WHO support and the number of reported cases of human African trypanosomiasis (HAT) fell from over 37,000 in 1998 to under 10,000 in 2009 (Simarro et al., 2011). These results have raised hopes for the control and elimination of HAT.

In addition to HAT, animal Africa trypanosomiasis (AAT) persists across the continent (Messina et al., 2012). The disease is economically debilitating and is estimated to reduce livestock productivity by 20-40 per cent in tsetse-infested areas (Hursey, 2001). AAT presents a problem to many communities and people in Africa. The threat of climate change, which may alter patterns of tsetse distribution, raises concerns for many pastoralists and commercial livestock operations on the continent (Messina et al., 2012).

This paper begins by tracing the history of tsetse control on the northern fly-belt in Zimbabwe, which attracts the Mashonaland East, Mashonaland Central and Mashonaland West provinces. It is commonly agreed that, as a consequence of the very low birth rate of tsetse of all species, the most effective approach to the control of human and animal trypanosomiasis lies in the control of the vector (Hargrove, 2003). In Zimbabwe, tsetse control shifted and evolved in the twentieth century, ranging from the initial methods of game destruction and bush-clearing to ground and aerial spraying of insecticides, the sterile insect technique (SIT), tsetse trapping, and the use of insecticide applied to cattle or to artificial baits called targets. The second part of the paper looks at the possible effect of climate change on the abundance and distribution of tsetse by considering how changes in temperature and vegetation patterns could affect life cycles and breeding patterns. The analysis offers suggestions for the means of alleviating the future effects of any alteration in human-tsetse contact resulting from changes in climate, land use and human populations.

The History of Tsetse Control Methods in Zimbabwe

A range of methods has been used in Zimbabwe and Rhodesia since 1900 to combat tsetse flies and the spread of trypanosomiasis. The most prominent have been game destruction and bush clearing, aerial and ground spraying, baited and insecticide treated target, and insecticide treated cattle.

Game Destruction and Bush Clearing

Game destruction and bush clearing were the first large-scale programs put into place to eradicate tsetse fly in Rhodesia. The rinderpest outbreak of 1896-97 vastly reduced game and cattle populations across southern Africa, and tsetse disappeared with them. However, as the game numbers recovered, so did the tsetse, and with them, the number of cases of trypanosomiasis. This recovery coincided with the expansion of African and European livestock numbers, which in many cases had expanded into areas that had been free from tsetse due to the rinderpest epizootic (Gargallo, 2009). The Agriculture and Veterinary Department was emphatic in its early assessment of the disease. It felt the fly was a “serious danger to domestic animals, and the extermination of big game in the infected areas is the only means of getting rid of this pest” (Gargallo, 2009, p. 741). Over the next several decades, “in the tsetse fly eradication campaigns, close to a million animals were … slaughtered in order to create buffer zones between resistant game and European land or farms” (Mutwira, 1989, p. 250). Game destruction was officially adopted by the government in 1933 (Chadenga, 1992). While the eradication campaigns were extensive, and often successful in many areas (Ford, 1971), they raised opposition from Africans and Europeans. Conservationist movements such as the Society for Game Preservation and the Natural Resources Board raised considerable objections. So too did the Hunters Association and others affiliated with the hunting lobby. In addition, as White (1995) has shown, the system was riddled with abuse and open to exploitation. By the 1950s, wholesale game eradication fell away as official policy and was replaced by other less contentious methods. The game destruction was not cheap either. The cost of hiring hunters and assistants to travel to remote areas was high, and the impact in areas was hard to verify (Gargallo, 2009; Ford, 1971).

Bush clearing was another tactic employed to try to control the fly's presence. From 1955-1960, bush clearing aimed at denying refuge sites to tsetse flies was thought to be an effective measure to control the fly (Ford, 1971; Chadenga, 1992). However, such programs were never particularly effective, were hard to maintain, and also engendered opposition from conservationists.

Aerial and Ground Spraying

The advent of insecticidal methods of controlling and eliminating tsetse flies changed the face of trypanosomiasis control in the 1950s and 1960s. Across Africa, "well organized trypanosomiasis control organizations showed it was possible to move from defense to attack in the battle against tsetse" (Barrett, 1991). In Zimbabwe, tsetse control officers adopted applied ground spraying techniques that had been used in other parts of the continent. Initially the spraying was done using dieldrin and switched to the cheaper DDT after a few years. It was used across the country to great effect (Lovemore, 1999). Ground-spraying worked on the basis that tsetse flies spend much of their life "resting in cool, shady places provided by trees [and] holes … and directing a persistent insecticide at these sites should achieve a good control measure" (Chadenga, 1992). Reports by Cockbill (1967) and Robertson and Kluge (1968) indicated positive results from large programs employing this tactic in the south-east districts of Zimbabwe, as well as in joint operations with South Africa and Mozambique.

Aerial spraying was first tried in Zimbabwe in the 1950s. However, it was initially very costly. In the 1960s, it became cheaper and was used more widely. Sequential, ultra low volumes of insecticide (in Zimbabwe, this was mostly *endosulfan* at 20-24 g/ha.) were used to target large areas of tsetse-infested regions. Hursey and Allsopp (1983) have demonstrated that the technique was feasible and produced quick results for dealing with emergency situations. During the height of the liberation war (1976-1979), tsetse control measures ceased in many parts of the country. As a result, the northern fly-belt expanded as tsetse reinvaded Zimbabwe from Mozambique and affected a large number of farming and communal areas. The densities of these fly populations were exceptional (Lovemore, 1999), and Zimbabwe joined the Regional Tsetse and Trypanosomiasis Control Program (RTTCP) after independence to combat the spread of the flies. Both ground and aerial spraying were used on a large scale in this operation with considerable results. The fly-belt was pushed back to its 1975 limits by the end of the 1980s (Lovemore, 1999: 27).

However, both aerial and ground spraying techniques have several disadvantages. With ground spraying alone, "it is difficult to consolidate areas that are cleared of tsetse flies, and this means that repeat spray applications are inevitable. This becomes expensive, as well as being a cause for environmental concern. In addition, ground spraying places heavy demands on transport, labour and strict operational supervision" (Chadenga, 1992). Due to these considerations, the Tsetse and Typanosomiasis Control Branch of Zimbabwe reduced the use of DDT in its control operations. Aerial spraying also faces challenges. It is particularly ineffective and dangerous in hilly terrain, and the operations are dependent on a high level of technical sophistication and the need for efficient and timely repeat sprayings. Both forms of spaying are also relatively expensive to undertake (see Table 1).

Table 1

Summary of Costs of Different Approaches to Tsetse Control in Zimbabwe 1990

Case A: Flat terrain with relatively easy access

Method	Direct Costs Z$/km^2	Indirect Costs Z$/km^2	Total Costs Z$/km^2
1) Aerial spraying with endosulphan	900	250 – 500	1150–1400
2) Ground spraying with DDT	400	50 – 90	450–490
3) Targets at 1 per sq. km.	120	50 – 90	170 – 210
4) Targets at 4 per sq. km.	400	50 – 90	450–490
Cattle Decatix dipping	60	These are insecticide costs only (1990)	
Spot on application	165	(at 10 head of cattle per square kilometre)	

Case B: Rugged terrain with difficult access

Method	Direct Costs Z$/km^2	Indirect Costs Z$/km^2	Total Costs Z$/km^2
1) Ground spraying with DDT	470	200–350	670–820
2) Targets at 1 per sq. km.	170	250–400	420 – 570
3) Targets at 4 per sq. km.	500	250–400	750–900
4) Ground spraying with deltamethrin	950	200–350	1150–1300

Source: Chadenga, 1992.

In Botswana, aerial spraying has been used to great effect and has resulted in tsetse being eradicated in that country. The particular improvement in the efficacy of aerial spraying in Botswana resulted from the use of effective GPS systems, which allowed highly specific and targeted spraying (Kgori et al., 2006), combined with operations over much larger areas. Similar techniques are likely to be used in Angola, Namibia and Zambia, where the generally flat terrain is more suited to this form of control and eradication.

Odor Baited and Insecticide Treated Targets

It has been shown that the low reproductive rates of tsetse mean that the kill rate needs only to be relatively low in order to have a major control effect (Hargrove, Torr, & Kindness, 2003). This can be achieved with targets. The first trial of odor baited targets in Zimbabwe was undertaken on an island of 5 km^2 in Lake Kariba (Vale et al., 1986). This was swiftly followed by a larger trial of 600 km^2 in the Zambezi Valley (Vale et al., 1988). The aim was to control tsetse flies by attracting them to visual targets, which are baited with odor attractants and coated with insecticide. The trials indicated that the method could work for large-scale campaigns and offered a number of advantages over other methods of control. The targets were relatively cheap, non-intrusive and environmentally friendly, and could work both in flat or rugged terrain. A major benefit of the targets is that they limit reinvasion of cleared areas. Targets were deployed at four per square kilometer throughout much of the northern fly-belt region as part of the RTTCP activities, and were highly effective in the Umfurudzi wilderness area and areas south of Lake Kariba (Chadenga, 1992). By 1990, 54,000 targets were deployed across Zimbabwe. Table 1 shows the cost per km^2 of the odor baited targets in 1990.

Since 1990, tsetse control technologies and methods have continued to evolve. However, across many parts of Africa, Zimbabwe included, the economic downturn and the limitations of structural adjustment programs have reduced the funds available to continue research (Scoones, 2014). Recent innovations in research have led to the development of insecticide treated screens (or tiny targets) to control flies more cost-effectively. Shaw et al. (2015) have reviewed a 250 km^2 field trial of tiny targets in Northern Uganda. They estimated that the cost of the operation at US$85.4/km^2, which represents a "major reduction in the cost of tsetse control." The low cost per km^2 is largely due to the low costs of tiny targets and to the ease with which they can be deployed.

Insecticide-Treated Cattle

The application of insecticides directly to cattle was re-instated in the 1980s and 1990s. While the technique had been used since the 1940s, improvements in chemicals and application techniques, as well as improved understanding of fly behavior, have seen this approach yield impressive results (Hargrove et al., 2012; Torr et al., 2011; Torr et al., 2007; Hargrove et al., 2003). The insecticide can be either be applied as a dip spray or as a pour-on formulation. The pour-on approach, applied monthly, is less error prone, and has been proven more flexible and adaptable in more remote regions, while allowing herders to adapt the approach as necessary (Swallow et al., 1995). However, this pour on method is relatively costly. The lower cost of the dip spray, and the ability to combine it with tick control, makes this a very cost-effective measure to curb AAT (Chadenga, 1992).

Despite these various control measures, neither tsetse nor trypanosomiasis have been eradicated in northern Zimbabwe. Recently, there was a spate of new cases of HAT in northern Zimbabwe, and a number of new programs and initiatives are underway to address this issue (Scoones, 2016). With the radical changes in rural livelihoods and settlement patterns that have occurred in Zimbabwe since the start of the fast-track land reform program in 2000, "it is still unclear how the reconfigured land use and occupation structures have changed exposures to trypanosomiasis" (Dzingirai et al., 2013). In addition, the potential long-term affects of climate change have also been unclear. Changes in climate could dramatically impact the fly belts, either enlarging or reducing them, depending on the changes that take place, and how these affect tsetse population growth rates and habitations.

Current Fly Infested Areas in Northern Zimbabwe

Tsetse still occupy the lowveld areas of the Zambezi valley along the border with Zambia and Mozambique. Despite the range of interventions in Zimbabwe over the past 30-40 years, conditions in the lowveld, plus the continued reinvasion of flies from Zambia and Mozambique, mean that the fly still has a foothold in the region. In addition, it has been noted that shifts in vegetation patterns have resulted in the fragmentation of tsetse habitat (Scoones, 2014). As a result, particular patches of habitat exist, beyond the escarpment and in the interior of Zimbabwe, that can and do host small fly populations that reside closer to more populated areas. Human interactions with these pockets of fly-holding vegetation have increased due to events in Zimbabwe over the last two decades. As grazing areas have been depleted, herders have moved further onto the edges of wildlife areas. Food and water shortages have pushed people to forage closer to these infested zones, and land reallocation has put people in areas that were not previously occupied. All of this has contributed to increased exposure and could explain the increased HAT cases. Vale (1988) has pointed out that while these pockets of vegetation contain flies all year-round, they might also be supplemented by seasonal movement of flies from lower areas. They probably do not reproduce in these areas, but migrate when conditions are right and 'repopulate' these zones at certain times rather than permanently occupy them (Jack, 1939). Nevertheless, these fly populations present significant risks to the human and cattle populations around them.

Climate Change in Northern Zimbabwe: Possible Scenarios and Effects on Fly Populations

Since 1900, much of southern Africa has progressively experienced warmer temperatures. Sango and Godwell (2015) have pointed to a historic trend that in the Makonde district (in Mashonaland West and close to the tsetse zones of northern Zimbabwe). Using data from the meteorological services in Zimbabwe, they found that the mean average annual temperature has increased over 0.5 degrees Celsius from 1962 to 2008. Some have posited that the fly belts will expand due to climate change and global warming (Dzingirai et al., 2013). It is recognized that there are a variety of factors that affect the tsetse distribution, including temperature, rainfall, humidity, vegetation and food sources, as will be discussed below. However, the rise in average temperatures may have two important impacts on the tsetse fly distribution:

1. It may make the Lowveld more inhospitable to flies and directly impact breeding patterns and survival rates. Despite the continued presence of the tsetse in northern Zimbabwe, the overall fly population seems to have fallen. Hargrove and Ackley (2015) have illustrated that after the droughts and heat waves of 1992 and 1994/1995, catches of adult flies dropped markedly, indicating a drop in the total fly population. In 1992 between 16 October and 4 November, the lowest daily maximum temperature was 38 degrees Celsius, and the average maximum temperature was 40.2 degrees Celsius. The catches of fly numbers increased during 1993, but then in November of 1994 and October 1995, the mean maximum temperatures were 37.8 degrees Celsius and 38.1 degrees Celsius respectively (Hargrove and Ackley, 2015). These heat waves, so close together, have had an impact on the total fly numbers in the Zambezi Valley in two main ways. First, the high temperatures themselves killed flies, particularly teneral flies, unable to survive in these temperatures. Second, these

heat waves also coincided with the lowest recorded rainfall in the area. As a result, fly numbers suffered not only from the effects of temperature, but in the view of Hargrove, also because of a decline in the number of mammalian hosts, which also died in large numbers due to the drought (Hargrove, 2003).

2. The rise in temperatures may make the Highveld areas currently unoccupied by flies more hospitable to fly invasion. Low winter temperatures on the Highveld have inhibited fly survival there. However, if these temperatures rise, so too do the chances of fly survival and reinvasion (Pollack, 1992).

As stated, there is a range of complicated modelling necessary to conclusively determine if the tsetse with flourish or flounder in northern Zimbabwe due to effects of climate change. Much of the data needed to undertake this modelling is not available. However, given what is known currently about the tsetse, it seems at least likely that there is a possibility of an increase in fly populations. If this were to occur over the next several decades, what would be the implications? This is the focus of the rest of the paper.

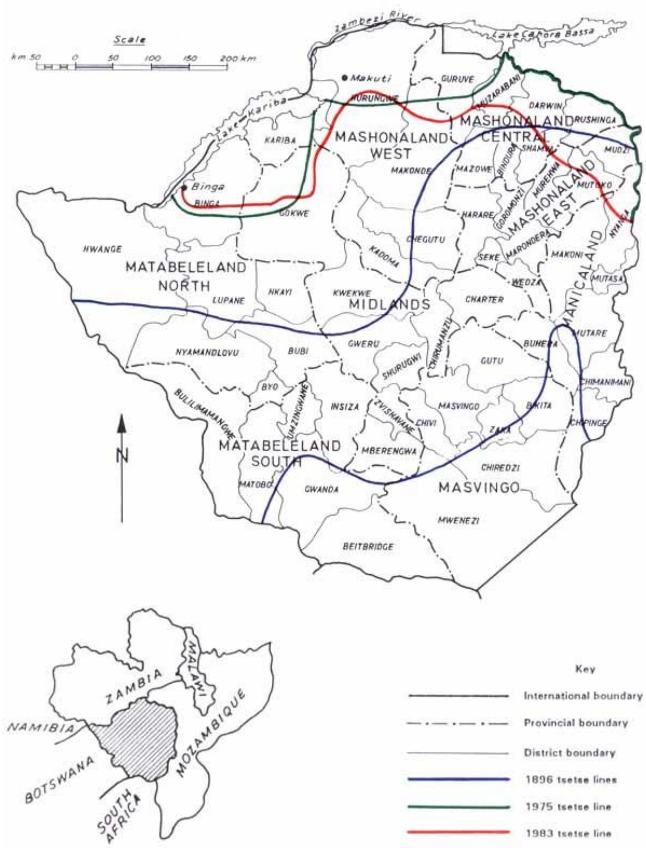

Figure 1. Extent of the Tsetse Reinvasion in Zimbabwe in 1983 (Lovemore, 1994)

Desmond Lovemore (1999) illustrated the historic extent of the fly belts in northern Zimbabwe, and how these have shifted over time. Successful control measures such as host eradication, bush clearing and spraying pushed flies back from the 1896 extent (the blue line in the Map. However, the halt to control measures due to the Liberation War in the late 1970s saw the flies reinvade previously cleared areas, particularly in the north-east section of the country.

The obvious threat here is that without continued protection measures, and the possible influence of climate change, tsetse could reinvade much of northern Zimbabwe, which would cause fly related problems for much of Matabeleland North, the Midlands, Mashonaland West and Mashonaland Central.

As Cockbill (1982) warned:

> In Zimbabwe, where agriculture and particularly stock raising are of major economic importance, the control of the tsetse fly, leading to its total eradication is a task of national importance. If control measures were suspended or became ineffective, tsetse could again spread to its ecological limits and occupy about half of Zimbabwe as they did before 1896. If this were to happen, about a third of the national herd would be threatened with disaster. Capital losses would involve not only animals, but also the cost of buildings, dairies, dips, crushes and fences ancillary to livestock production. Rural society would suffer large-scale cattle losses. (Lovemore, 1984)

Table 2

Population per District (thousands)

MATABELELAND NORTH	
Victoria Falls	34
Hwange	38
Binga	140
Lupane	100
Nkayi	109
MIDLANDS	
Gokwe North	240
Gokwe South	305
Kwekwe	175
MASHONALAND WEST	
Kariba	41
Hurungwe	329
Makonde	154
Sanyati	113
Chinhoyi	78
MASHONALAND CENTRAL	
Mbire	82
Guruve	124
Muzarabani	123
Mount Darwin	213
Rushinga	74
MASHONALAND EAST	
UMP	113
Mudzi	133
Mtoko	148
TOTAL	2866

As per the findings of the 2012 population census, if the fly belt extended to the pre-1900 extent, the number of people effected would be in excess of 2.8 million people. (See Table 2).

This is a significant population that would have to contend with the associated risks of living in tsetse infested areas. In addition to the human population, many of these areas have large cattle populations. The northern parts of Mashonaland have traditionally been areas well stocked with cattle. However, exact numbers are hard to ascertain. According to the Comercial Farmer's Unit (CFU), the total national herd was estimated at 5.5 million in 2016 with 90 per cent of this in smallholder farming areas, but numbers have been declining due to the current drought. It may be up to one third of the national herd in this region, meaning 1.8 million cattle would be at risk from AAT (Lovemore, 1999). As Cockbill (1982) has noted, the resulting influx of flies would result in capital losses of livestock and a large negative impact on rural livelihoods.

However, since 2000 there have been a number of social, environmental and economic changes in northern Zimbabwe, which could temper possible fly invasions. Since the implementation of the fast-track land reform program in 2000, the commercial farming sector has all but been eradicated, replaced largely with small-scale farming. The result has been an increased spread of human populations, as land previously reserved for commercial use (cropping, ranching, game reserves, etc.) has now been settled by small-scale farmers from urban and communal areas. These new forms of settlement have resulted in more land being cleared for farming, e.g. diminishing vegetative covers tsetse flies can use. The growth in contract tobacco farming and the significant rise in small-scale tobacco farmers have put huge pressure on environmental resources. In 1999, there were fewer than 5,000 communal or small-scale tobacco farmers. This increased to over 90,000 in 2013 and then to 130,000 in 2015. These farmers have mostly relied on firewood to cure their tobacco. At the end of 2013, it was estimated that 300,000 square kilometres of tree cover was being lost a year due to tobacco farming in Zimbabwe. While this is taking place across the country, the northern regions of Mashonaland are prime tobacco areas, so much of this deforestation is taking place in areas to which flies might occupy. Since 2000, the rise in settlers and human populations has had adverse affects on the wildlife populations, due to poaching, resource extraction and loss of habitat (Rademeyer, 2016). This means that vegetation cover has been lost as well as a range of animal hosts for tsetse. However, to temper this loss of wildlife, many small-scale farmers have livestock, such as cattle, that the flies can feed on.

As noted above, there is evidence that patches of habitat exist beyond the escarpment and in the interior of Zimbabwe that can and do host small fly populations that reside closer to more populated areas (Scoones, 2014). These pockets, closer to human activity, threaten cattle and human health. With the possible effects of climate change these pockets could be important areas that allow the flies to gain a foothold in the Highveld.

Control and Policy Issues

If increasing temperatures were to make the Highveld more hospitable to tsetse leading to possible reinvasion and an increase in fly numbers, methods for controlling flies would have to adapt accordingly. These invasions may pose significant threats to human and livestock populations, particularly because of people's reliance on livestock and the importance of the rural economy. Shaw et al. (2014) have shown in a detailed study of Ethiopia, Kenya, Somalia, Sudan and Uganda that the mean benefit over a 20-year period, since the absence of AAT is approximately US $3,335 per square kilometer. These countries, and the cattle production systems practiced there, are very different to the Zimbabwean context. However, the study illustrates the potential importance of continued tsetse control in northern Zimbabwe.

Understanding the drivers of this possible reinvasion (as outlined above) and conditions on the ground reveal what the best control measures would be. For example, considering that the flies will rely mostly on scattered vegetative outcrops to survive, strategic placement of baited traps in corridors of fly travel/migration, as well as around these vegetation outcrops could yield significant results and keep flies in check. In addition to baited traps, if there was a concerted effort to ensure that livestock of those in proximity to these outcrop areas were insecticide treated, controlling the spread of these new populations of flies could be relatively easy.

Shaw et al. (2013) have estimated the costs of various tsetse control measures in Uganda. For the creation of fly free zones, the field costs per square kilometer were US $283 for baited traps (4 traps per square kilometer), US $30 for insecticide treated cattle (ITC - 5 cattle per square kilometer), US $380 for sequential aerosol technique (SAT) and US $993-1,365 for sterile insect techniques (SIT). For areas where continuous tsetse control operations were necessary, Shaw et al. estimated the costs for a 20-year period, and put the costs at US $368 for ITC, US $2114 for traps (all deployed continuously), and US $2,442 for SAT (applied at three year intervals).

These costs and estimates would not be directly transferable to the Zimbabwean context. In Zimbabwe, such costs are likely to be higher, due to the US dollar being the principal currency, higher import costs, wage demands and greater area to cover. However, what Shaw et al. (2013) illustrate is that baited traps and the ITC are the cheapest forms of control currently in use. Indeed, as Chadenga (1992) has noted, the ITC and trap costs in Zimbabwe during the 1990s were also the most cost effective means of tsetse control.

Along with these direct control measures, community outreach campaigns should be implemented to ensure that there is a significant level of community buy-in to these tsetse control measures. Whilst these activities may drive up the costs, research has illustrated that community participation in trap maintenance and cattle dipping significantly improve results (Shaw et al., 2014; Dransfield & Brightwell, 2004). Also, whilst the insecticide treated cattle will be protected from tsetse flies, there is additional benefit in guarding against other parasites and pests. Furthermore, as Scoones (2014) has observed, communities in areas with vegetative outcrops are often aware of which areas are populated with tsetse and a threat to both animals and humans. Community members can then assist with the deployment of traps and specific targeting of key areas, reducing costs and time in the field.

Of course, for these interventions to work, they would require investment and support from the state. Tsetse control operations in Zimbabwe have decreased in the last two decades due to the financial and political crises that have affected the country. However, possible climate change effects may result in tsetse and trypanosomiasis becoming much more pressing issues for many rural dwellers and livestock handlers over the next few decades.

Conclusion

This paper has traced the history of tsetse control in Zimbabwe. While tsetse flies still reside in northern Lowveld areas, many of the control measures have had a discernable impact. However, changes in the political, social and economic realities in Zimbabwe have meant that control measures have been curbed. At the same time, rising temperatures due to climate change raise the possibility that tsetse could reinvade the Highveld. This raises concerns that large populations of people and cattle will be exposed to the tsetse and the associated risks of AHT and HHT. However, as this paper has outlined, current control methods, including baited traps and treated cattle, would be efficient in controlling this possible reinvasion, if implemented properly and while these fly populations are establishing themselves. This requires government support and clear policy guidelines to ensure that control measures are enacted. The benefits to the human inhabitants and their livestock are obvious, and the potential long-term development benefits clear.

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