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Towards a rational policy for dealing with tsetse

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The past 20 years have seen the development of bait technologies that enable livestock keepers to control tsetse flies and, hence, African trypanosomiasis. The techniques have, however, often been applied on too small a scale, without due regard to the realities of tsetse population dynamics. The consequent lack of progress has led to calls for a return to large-scale operations. Analysis of successful programmes to control or eliminate tsetse in southern Africa suggests that the combined use of recently improved bait methods and insecticide spraying will provide the building blocks for achieving the wider objective of the African Union, which is to create large tsetse-free zones.

The way we were

In the mid-1980s, the days of tsetse seemed numbered. In southern Africa, a programme to eliminate tsetse from a 'fly belt' of 320 000 km^2 covering Malawi, Mozambique, Zambia and Zimbabwe was initiated with support from the European Union [1]. In East Africa, a UK-supported project aimed to use aerial spraying to eliminate the main tsetse infestation in Somalia. In Zimbabwe, ground spraying and aerial spraying were used to control tsetse over ~10 000 km^2 annually [2], and in West Africa riverine species of tsetse were controlled with traps [3].

Other technologies that are more cost effective were also developed. Odour-baited targets were used successfully on a large scale [4], and work in Zimbabwe showed that pyrethroid-treated cattle might even be more cost effective [5]. The technologies, money and people needed to control tsetse were, thus, in place and even environmental concerns about large-scale tsetse control seemed calmed [6]. Consequently, the late 1980s saw a general increase in the number of large operations and the use of bait technologies [2,3,7].

Small is beautiful?

During the 1990s, however, progress and prospects changed. European donors, major supporters of tsetse control, abruptly shifted spending to other areas. Under the political and economic view of the day, livestock ownership was a commercial enterprise and those who benefited directly from it should, accordingly, fund tsetse control. This view was made feasible only by the newly developed bait technologies that, in contrast to spraying operations, could be applied by local communities.

Unhappily, the result of this policy was that the effective new tools of odour-baited targets and insecticide-treated cattle were applied on inappropriate scales. Moreover, the policy of community participation was applied without due regard to the dynamics of tsetse populations and their control. The basic reason for this is that the scale of community-based operations is governed by the social factors that enable groups of livestock keepers to cooperate. Consequently, the operations covered areas of just 50–500 km^2 [8], compared with the 5000–10 000 km^2 tackled by aerial and ground spraying. But the mobility of tsetse means that, even if baits were optimally deployed, tsetse could penetrate ~5 km into a control area [4]. Consequently, an operation covering 100 km^2 and surrounded by infested land could not eliminate tsetse. Moreover, community-based control operations are dependent on pooling private resources to achieve a 'public good'. Problems inherent in any collective action, allied to a lack of technical advice and the economic constraints faced by poor communities in rural areas, mean that effective baits are seldom optimally deployed [9]. The demands of grazing and watering livestock also mean that, even if cattle were treated adequately with insecticide, they would still be distributed patchily. In these circumstances, invasion of the control area is exacerbated and trypanosomiasis control is not effective [10].

Livestock owners do, however, have an important role in trypanosomiasis control; each year, they administer ~35 000 000 doses of trypanocides, at approximately US$1 per treatment, to cure or prevent the disease [11]. This easy intervention requires no liaison with neighbours, and the benefits are rapid, obvious and accrue entirely to the implementer. Thus, farmers choose to treat the disease rather than prevent it and would probably engage appreciably in tsetse control only if it were as cheap and simple as using drugs.

This goal might yet be achieved using insecticide-treated cattle. Insecticide usage can be reduced by ~90% by treating only the larger cattle within a herd and only the legs and belly, where most tsetse feed [12,13]. Moreover, pyrethroid prices have declined as patents have expired and commercial competition has increased. Consequently, tsetse control in cattle areas might be achieved for less than US$1 per animal per year [14]. The new technique reduces the need for plunge dips and is

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Box 1. Control, eliminate or eradicate?

Tsetse control is the deliberate reduction of fly numbers to locally acceptable levels, with the reduction being maintained by continued intervention. Elimination means the complete removal of a tsetse species from a defined geographical area. Eradication means the removal of all wild populations of a species. Extinction means the disappearance of the species from the planet [23].

It has been argued that, in the case of elimination, 'continued intervention is required' [23]. However, although *Glossina pallidipes* has been eliminated from South Africa, no intervention against this species has been required since the 1950s. Similarly, no intervention has been required against *Glossina morsitans morsitans* in the southeast of Zimbabwe for 25 years.

Perpetual tsetse and trypanosomiasis control, on the one hand, and complete continental eradication of all tsetse species, on the other hand, are not the only options available. Local elimination, as in South Africa, has saved thousands of cattle and millions of dollars in drugs and tsetse-control efforts during the past 50 years – despite the existence of *G. pallidipes* in neighbouring Mozambique and Zimbabwe, and even the continued existence of two other species of tsetse fly in South Africa. Local elimination can, therefore, make excellent long-term sense without being extended to the whole continent or, even locally, to all tsetse species.

The relative benefits of eliminating or controlling tsetse depend crucially on the time period and the levels of costs and benefits. For example, discounted at a rate of 10% over 25 years, a one-off expenditure of US$1000 per km^2 to eliminate a population is equivalent to an annual expenditure of US$100 on control [24].

In this regard, we support the decision of PATTEC to focus its activities first on isolated tsetse belts in areas where local elimination would have obvious economic benefits.

now, arguably, simpler than trypanocide treatment, which requires careful attention to trypanocide preparation, dilution and weight-related dosing [11]. Furthermore, by restricting the application of insecticide, the risks of environmental damage or exacerbation of tick-borne diseases, through the development of acaricide resistance or disruption of enzootic stability, are reduced [15].

By itself, however, this use of insecticide-treated cattle will not eliminate tsetse from Africa, regardless of issues of economy or scale. The distribution of cattle is too patchy; national parks are often cattle free and, even within farming areas, cattle are not distributed evenly. Thus, tsetse persist in cattle-free areas to reinvade the controlled areas.

Human population growth and agricultural expansion are bringing profound environmental changes to Africa and, with them, the epidemiological balance of trypanosomiasis is shifting. Domestic livestock is replacing the natural wild hosts of tsetse and trypanosomes and, as a result, trypanosomiasis is shifting towards a less virulent form with lower rates of infection. Under these circumstances, it has been argued [16], area-wide elimination of tsetse is unnecessary because the combined use of insecticide-treated cattle and trypanocidal drugs, and the continued anthropogenic changes in habitat within farming areas will provide cost-effective and sustainable control of tsetse and trypanosomiasis. However, this approach has its problems, such as the extensive and increasing resistance to trypanocidal drugs [11].

If we wish to eliminate (Box 1) tsetse from large areas [17], to provide permanent relief from trypanosomiasis, we must return to large-scale campaigns and to the view that

Box 2. Area-wide control of tsetse in Zimbabwe

In the early 1980s, immediately after the disruption caused by the Liberation War, Zimbabwe faced a rapidly rising incidence of animal trypanosomiasis (Figure I). Between 1980 and 1999, the Zimbabwe Department of Veterinary Services carried out extensive operations against tsetse using a combination of ground spraying with DDT, aerial spraying with endosulfan, odour-baited targets impregnated with deltamethrin, and deltamethrin-treated cattle (Figure IIa). The estimated costs of the techniques were US$265–390 per km^2 for ground spraying, US$435–535 per km^2 for aerial spraying, US$220–385 per km^2 for targets and US$120 per km^2 for cattle [24]. Operations before 1986 comprised mostly ground spraying and aerial spraying but, thereafter, these technologies were gradually replaced by bait technologies so that, by 1991, only targets and insecticide-treated cattle were in use [7].

The impact of these operations is shown in Figure IIb. In the early 1980s, trypanosomiasis occurred across a swathe of northern Zimbabwe, with the annual number of cases exceeding 10 000 in 1984 (Figure I). By 1990, the combined use of all techniques reduced the annual number of cases recorded nationally by >90%; continued control, using bait technologies alone, brought the national incidence down to <100 cases per year by 1995, where it remained until 1997 when extensive monitoring of trypanosomiasis ceased.

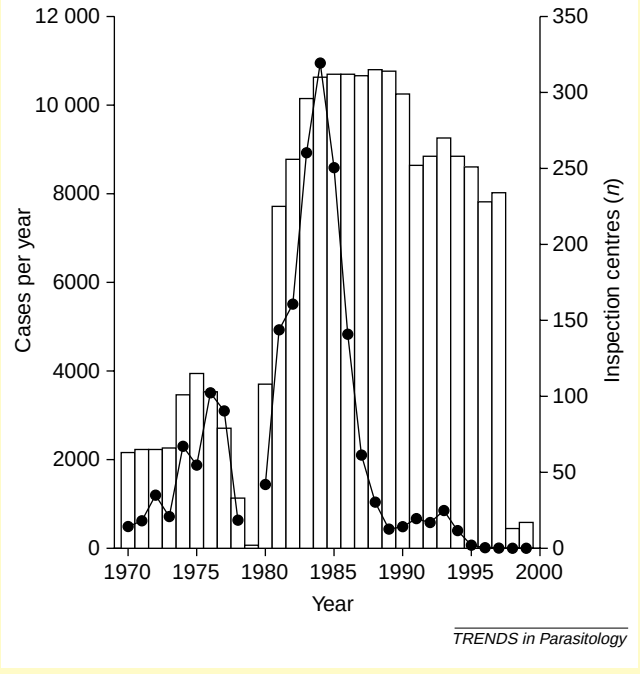

Figure I. Annual number of trypanosomiasis cases in Zimbabwe recorded at *n* veterinary inspection centres between 1970 and 1999. The number of trypanosomiasis cases is represented by dots (left *y*-axis) and the number of veterinary inspection centres is represented by bars (right *y*-axis). Discontinuity in 1979 was due to the disruption in veterinary monitoring caused by the Liberation War. Data derived from Ref. [25] and from unpublished results of S. Torr.

control or elimination of tsetse populations is a 'public good' that requires central funding, planning and execution.

Back to the future?

Success stories of the past 20 years indicate a possible way forward [18]. In Zimbabwe between 1984 and 1997, aerial and ground spraying, odour-baited targets and insecticide-treated cattle eliminated tsetse from ~35 000 km^2, and trypanosomiasis disappeared from livestock (Box 2).

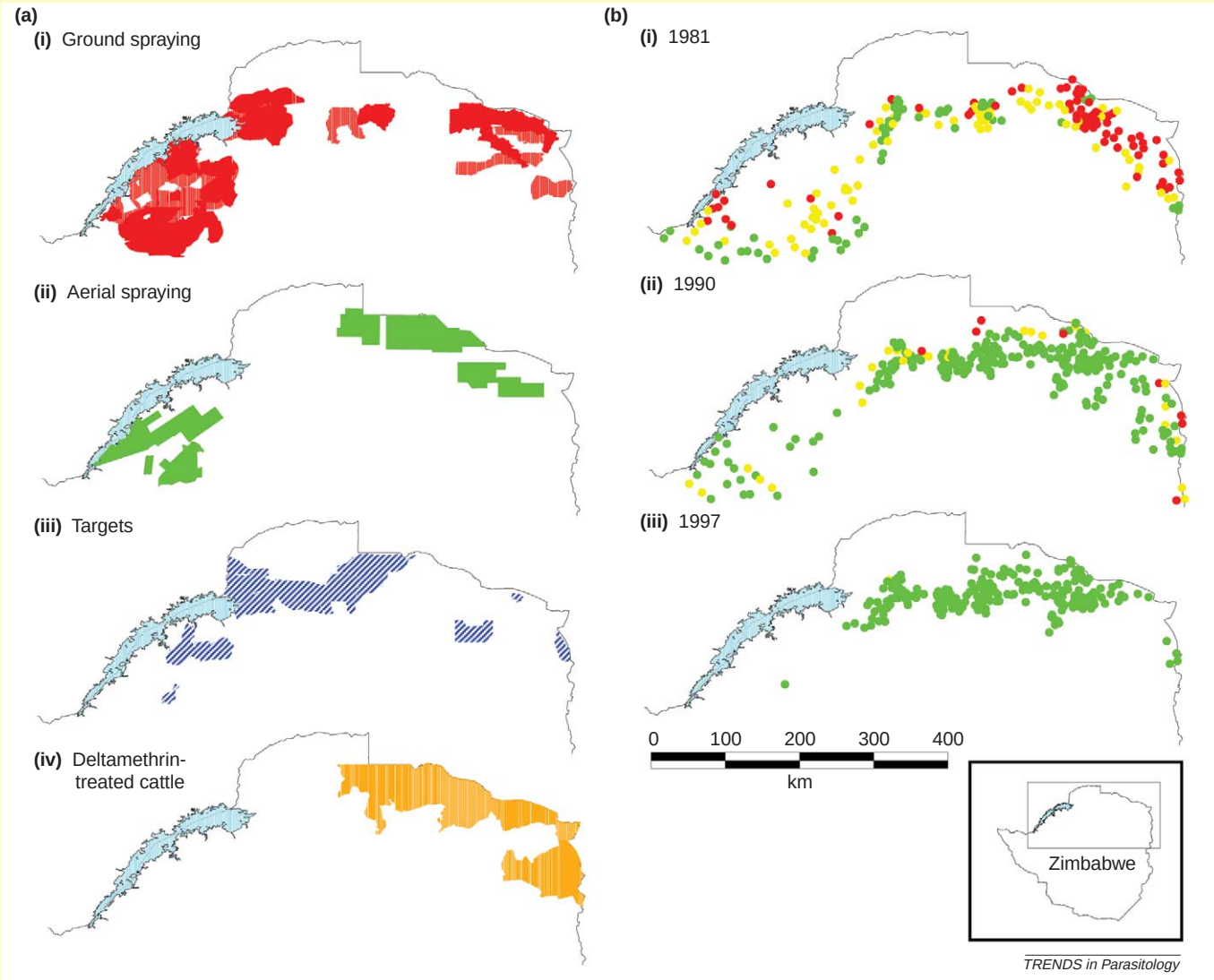

Figure II. Tsetse and trypanosomiasis control in northern Zimbabwe. **(a)** Extent of control operations conducted in northern Zimbabwe between 1980 and 1999. The operations used (i) ground spraying with DDT, (ii) aerial spraying with endosulfan, (iii) odour-baited targets impregnated with deltamethrin or (iv) deltamethrin-treated cattle. **(b)** Veterinary inspection centres in northern Zimbabwe recording the presence or absence of bovine trypanosomiasis. Data were obtained in (i) 1981, (ii) 1990 and (iii) 1997. Yellow dots = 1–9 cases per year of bovine trypanosomiasis; red dots = >9 cases per year. Green dots represent the absence of bovine trypanosomiasis. Data in (a) and (b) are derived from Refs [25–29] and from unpublished results of S. Torr.

Similarly, tsetse were cleared from 11 500 km^2 of the Western Province of Zambia using odour-baited targets and, as in Zimbabwe, the cleared area was protected using target barriers. In the Kagera region of Tanzania, spectacular reductions in tsetse populations and trypanosomiasis were achieved over an area of 2500 km^2 using insecticide-treated cattle. In Botswana, 16 000 km^2 of the Okavango Delta were treated in two years using aerial spraying. No tsetse has subsequently been captured in the Delta (P. Kgori, personal communication). The success of this operation owed much to the development of new guidance systems for the aircraft used and to the application of insecticide over much greater areas than before [18].

Thus, ground spraying, aerial spraying, artificial baits (i.e. traps and targets) and insecticide-treated cattle provide four manifestly effective methods of tsetse control that can be applied, singly or in combination, to suit the ecological, social and economic demands of a particular area. All control operations, of course, face the same problem of tsetse reinvading from neighbouring areas. This is especially serious for ground spraying and aerial spraying, which, in contrast to bait technologies, are not applied continuously. For each year that a tsetse front is pushed back by, for example, aerial spraying, up to 20 km could subsequently be lost to reinvading flies [19].

Moreover, although effective spraying operations can eliminate tsetse from large areas, small foci of flies often remain. Bait technologies are then particularly valuable because traps can be used to identify sources of invasion and surviving foci, and insecticide-treated targets can, effectively and cheaply, prevent reinvasion and eliminate the foci.

Where do we SIT?

The foregoing suggests that the tools necessary to eliminate tsetse under a variety of circumstances are

available. What remain are the much more difficult and contentious issues of policy, financing, and organizational and executive capacity.

On the policy front, the prominence of the sterile insect technique (SIT) in plans formulated by the Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) has stimulated much argument [20]. Despite the use of this technique to eliminate *Glossina austeni* from Zanzibar, there are concerns about its cost [21] and that the inherent mobility and longevity of tsetse, and the way they transmit disease make SIT inappropriate [14]. Moreover, SIT requires the use of insecticide-based techniques to suppress the tsetse population by $>90\%$ initially and then provide protection from reinvasion. A technique that can provide these levels of suppression and protection should also be able to eliminate a population [22,14]. Conversely, the crucial role of the suppression technique means that if suppression were impractical in a particular situation, so would be SIT. Hence, SIT is an unnecessary and expensive addition to the arsenal of weapons against tsetse. None of the successful tsetse-control operations referred to earlier required use of SIT.

Who controls the controllers?

In the wake of the PATTEC aim to eradicate tsetse [17], the African Development Bank (http://www.afdb.org/) recently approved a project worth US$80 000 000 to support large-scale tsetse-control operations using insecticide-treated cattle and SIT. Thus, there seems to be an increasing eagerness in Africa to provide financing for tsetse-control operations. Realistically, however, it must be envisaged that major external funding will be required if the PATTEC aim of eliminating tsetse from large areas is to be achieved. This, in turn, raises issues about who decides how campaigns are carried out.

Operational capacity is a headache for any tsetse-control plan. Most African tsetse-control organizations are, where they survive, moribund. The challenge is, thus, to eliminate tsetse populations on a large scale without a government-funded tsetse-control department. The problem might not be as difficult as it seems. International companies carried out successful aerial-spraying operations in Somalia and Botswana that relied minimally on local tsetse expertise. Private contractors in Zambia [18] successfully deployed odour-baited targets – and the application of insecticide to cattle is effected even more easily by the private sector.

The attractive features of this approach are that: (i) the work can be done contractually, rather than involving the resurrection of complex and expensive bureaucracies; (ii) tsetse control becomes an exercise that recruits skills from wherever necessary; and (iii) competitive tenders would force contractors to look for the cheapest effective way of achieving the desired result within the stipulated time and conditions. This has the further advantage of moving the debate on appropriate control methods from the academic forum to the market place, where it ultimately belongs.

We have noted cases in which this approach has been successful. In other instances it might be politically unacceptable, but the hard facts are that neither African governments nor donors are likely, in the foreseeable future, to fund national tsetse-control departments akin to those of the colonial era. That being the case, the choice might realistically be between, on the one hand, elimination exercises involving international expertise and direction where necessary and, on the other hand, an indefinite reliance on small-scale control of tsetse and trypanosomiasis.

Moving on

Previous initiatives to eliminate tsetse from large areas ultimately failed owing to political, ideological or socioeconomic instability. In southern Africa, for instance, wars in Zimbabwe and Mozambique caused a resurgence of tsetse in the 1970s, and a combination of ideological shifts and socioeconomic factors caused the Regional Tsetse and Trypanosomiasis Control Programme (RTTCP) to abandon large-scale operations in the 1990s. Present efforts will suffer a similar fate unless the wider issues affecting the political and economic stability of Africa are addressed. In the meantime, stockowners now have at their disposal not only trypanocides but also insecticides to treat cattle, which can be effective if applied on a sufficient scale. But the way forward (Box 3), given economic and political stability, is clear; the tools are available to control, and ultimately eliminate, tsetse in a variety of ecological and socioeconomic settings. These tools should be used to their best effect, with due regard to ecological and land-use issues, bearing in mind that the larger aim of tsetse control is to improve living conditions in Africa.

Concluding remarks

Improvements in aerial spraying and bait technologies during the past 21 years, coupled with fuller

Box 3. A way forward

Analysis in the text suggests a rational way to control or eliminate tsetse populations.

- The use of insecticide-treated cattle provides the cheapest technique, which should be used wherever feasible. With support from extension services and non-governmental organizations, this method can be used to control tsetse and reduce markedly the incidence of trypanosomiasis, especially if the recent improvements in this technique are adequately promoted.
- These operations, however, will vary in their success; isolated communities, or those closer to heavily infested areas, will see considerably less benefit. For these communities, a form of area-wide approach will be needed, and donors and governments should be encouraged to support operations that can convert an assemblage of small, community-based control operations into a larger, area-wide one that can eliminate tsetse.
- Private contractors should deploy targets or conduct aerial-spraying operations to eliminate infestations that threaten areas being controlled by insecticide-treated cattle.
- Each operation would be a discrete intervention with its own limited endpoint but this mosaic of operations would have an impact greater than the sum of the parts. Achieving this synergy would require careful planning, and the development of user-friendly decision-support tools would be crucial [14]. This approach – with farmer-based operations functioning as the building blocks and with other techniques as the cement – would demand a change of emphasis in some of the current initiatives. In particular, greater effort would be required to help livestock keepers control tsetse themselves.

understanding of tsetse population dynamics and the importance of scale in tsetse-control operations, greatly facilitate the rational planning of tsetse control and elimination campaigns.

Uncited references

[26–29].

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References

1 Jordan, A.M. (1985) Tsetse eradication plans for southern Africa. *Parasitol. Today* 1, 121–123

2 Allsopp, R. and Hursey, B.S. (2004) Insecticidal control of tsetse. In *The Trypanosomiases* (Maudlin, I. *et al*., eds), pp. 491–507, CABI Publishing

3 Green, C.H. (1994) Bait methods of tsetse-fly control. *Adv. Parasitol.* 34, 229–291

4 Vale, G.A. *et al*. (1988) Odour-baited targets to control tsetse flies, *Glossina* spp. (Diptera: Glossinidae) in Zimbabwe. *Bull. Entomol. Res.* 78, 31–49

5 Thomson, M.C. (1987) The effect on tsetse flies (*Glossina* spp.) of deltamethrin applied to cattle. *Trop. Pest Management* 33, 329–335

6 Jordan, A.M. (1986) *Trypanosomiasis Control and African Rural Development*, Longman

7 Vale, G.A. and Torr, S.J. (2004) Development of bait technology to control tsetse. In *The Trypanosomiases* (Maudlin, I. *et al*., eds), pp. 509–523, CABI Publishing

8 Brightwell, R. *et al*. (2001) Reality vs rhetoric – a survey and evaluation of tsetse control in East Africa. *Agric. Human Values* 18, 219–233

9 Dransfield, R.D. and Brightwell, R. (2004) Community participation in tsetse control: the principles, potential and practice. In *The Trypanosomiases* (Maudlin, I. *et al*., eds), pp. 509–523, CABI Publishing

10 Hargrove, J.W. *et al*. (2003) Insecticide-treated cattle against tsetse (Diptera: Glossinidae): what governs success? *Bull. Entomol. Res.* 93, 203–217

11 Holmes, P.H. *et al*. (2004) Current chemotherapy of animal trypanosomiasis. In *The Trypanosomiases* (Maudlin, I. *et al*., eds), pp. 431–444, CABI Publishing

12 Torr, S.J. *et al*. (2001) Application of DNA markers to identify the individual-specific hosts of tsetse feeding on cattle. *Med. Vet. Entomol.* 15, 78–86

13 Torr, S.J. and Mangwiro, T.N.C. (2000) Interactions between cattle and biting flies: effects on the feeding rate of tsetse. *Med. Vet. Entomol.* 14, 400–409

14 Vale, G.A. and Torr, S.J. User-friendly models of tsetse control: application to the cost-effectiveness of sterile insect and insecticidal techniques. *Med. Vet. Entomol.* (in press)

15 Eisler, M.C. *et al*. (2003) Integrated control of vector-borne diseases of livestock – pyrethroids: panacea or poison? *Trends Parasitol.* 19, 341–345

16 Bourn, D. *et al*. (2001) *Environmental Change and The Autonomous Control of Tsetse and Trypanosomiasis in Sub-Saharan Africa*, Environmental Research Group

17 Kabayo, J.P. (2002) Aiming to eliminate tsetse from Africa. *Trends Parasitol.* 18, 473–475

18 Hargrove, J.W. (2003) *Tsetse Eradication; Sufficiency, Necessity and Desirability*, DFID Animal Health Programme

19 Hargrove, J.W. (2000) A theoretical study of the invasion of cleared areas by tsetse flies (Diptera: Glossinidae). *Bull. Entomol. Res.* 90, 201–209

20 Molyneux, D.H. (2001) Sterile insect release and trypanosomiasis control: a plea for realism. *Trends Parasitol.* 17, 413–414

21 Rogers, D.J. and Randolph, S.E. (2002) A response to the aim of eradicating tsetse from Africa. *Trends Parasitol.* 18, 534–536

22 Hargrove, J.W. (2005) Extinction probabilities and times to extinction for populations of tsetse flies *Glossina* spp. (Diptera: Glossinidae) subjected to various control measures. *Bull. Entomol. Res.* 95, 13–21

23 Molyneux, D.H. *et al*. (2004) Disease eradication, elimination and control: the need for accurate and consistent usage. *Trends Parasitol.* 20, 347–351

24 Shaw, A.P.M. (2004) Economics of African trypanosomiasis. In *The Trypanosomiases* (Maudlin, I. *et al*., eds), pp. 369–402, CABI Publishing

25 Lovemore, D.F. (1999) *Final Report for the Zimbabwe Component of the First and Second Phases of the Regional Tsetse and Trypanosomiasis Control Programme, Malawi, Mozambique, Zambia and Zimbabwe, 1986–1998*, Tsetse and Trypanosomiasis Control Branch, Zimbabwe

26 Hursey, B.S. and Allsopp, R. (1983) *Sequential Applications of Low-Dosage Aerosols From Fixed-Wing Aircraft as a Means of Eradicating Tsetse Flies (Glossina* spp.) from Rugged Terrain in Zimbabwe, Tsetse and Trypanosomiasis Control Branch, Zimbabwe

27 Hursey, B.S. and Allsopp, R. (1984) *The Eradication of Tsetse Flies (Glossina* spp.) From Western Zimbabwe by Integrated Aerial and Ground Spraying, Tsetse and Trypanosomiasis Control Branch, Harare, Zimbabwe

28 Allsopp, R. and Hursey, B.S. (1986) *Integrated Chemical Control of Tsetse Flies (Glossina* spp.) in Western Zimbabwe 1984–1985, Tsetse and Trypanosomiasis Control Branch, Zimbabwe

29 Shereni, W. (1990) Strategic and tactical developments in tsetse control in Zimbabwe (1981–1989). *Insect Sci. Application* 11, 399–409