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

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Abstract. A field trial in Zimbabwe investigated the efficacy of insecticide-treated cattle as a barrier to prevent the re-invasion of tsetse, *Glossina morsitans* and *G. pallidipes* (Diptera: Glossinidae), into cleared areas. The original tsetse barrier consisted of insecticide-treated odour-baited targets, at an operational density of four to five targets per km^2, supported by insecticide-treatments of cattle with either deltamethrin dip (Decatix®, Coopers) at two-weekly intervals, or deltamethrin pour-on (Spoton®, Coopers) at monthly intervals, in a band ≈ 20 km wide from the re-invasion front. Tsetse catch, and trypanosomiasis incidence in nine sentinel herds was recorded for 7–8 months, respectively, before the targets were removed, leaving only the insecticide treatment of the local cattle to stem the re-invasion of tsetse.

After the removal of the target barrier, the tsetse readily invaded the trial area and the incidence of trypanosomiasis in sentinel herds increased, while their PCVs decreased. After seven months without the targets in place, trypanosomiasis prevalence in the local stock had reached alarmingly high levels; the trial was terminated prematurely and the target barrier re-deployed. Immediately after the re-deployment of the target barrier, the tsetse catch in the trial area reverted to acceptable levels along the re-invasion front, and trypanosomiasis incidence in the sentinel cattle decreased.

It is concluded that, under the conditions of the field trial, the insecticidal treatment of local cattle did not in itself form an effective barrier to tsetse re-invasion. By contrast, the target barrier performed as was predicted by mathematical and experimental analysis, and readily cleared the tsetse infestation and reduced trypanosomosis incidence in the trial area.

Key words. *Glossina morsitans*, *G. pallidipes*, insecticide treated cattle, tsetse barriers, tsetse control, trypanosomiasis, Zimbabwe.

Introduction

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

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

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

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

Materials and Methods

The trial area

An area of 428 km^2 (≈ 40 km long and 5–15 km wide) adjacent to the Mozambique border and to the south of the Tete road in north-east Zimbabwe, was chosen for the trial (Fig. 1). Archive data showed that this area suffered a high invasion pressure from populations of both *Glossina morsitans morsitans* and *G.pallidipes* in neighbouring Mozambique (TTCB, 1992). Much of the area is heavily settled, although the distribution of settlement is patchy. The remaining land consists of a mosaic of alluvial woodland and dry forest, with patches of thicket adjacent to the Ruenya, Nyamusandzura and Mudzi rivers, which feed in a north-easterly direction through the trial area towards the Zambezi river. A cattle census revealed a population of between eight and twelve cattle per km^2 in the 428 km^2 of the trial area, which should be sufficient for an effective control of tsetse fly by insecticide treatment (Bauer *et al*., 1992). However, the cattle were not evenly distributed, reflecting the patchiness of the settlements, and we had no control over their grazing areas.

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

The target barrier was supported by an insecticide treatment of cattle in, and adjacent to, the barrier in an area some 20 km wide, west of the tsetse re-invasion front. Some 5400 head of cattle at three inspection sites in the area (Zano, Kapotesa and Nyamvu, Fig. 1) were dipped in deltamethrin 0.00375% (Decatix®, Coopers) at two-weekly intervals. After each dipping, the deltamethrin concentration in the dips was checked and, if necessary, adjusted. Whenever dipping could not be conducted (due to water shortage), the cattle were treated with pour-on deltamethrin, 1% (Spoton®, Coopers) at monthly intervals. The pour-on was applied in a line along each side of the animal, close to the dorsal mid-line, at a dose of 10 ml/100 kg body weight. Records were kept of the number of animals treated every month.

Tsetse monitoring

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

Trypanosomosis monitoring

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

At the start of the trial, all the sentinel animals were ear-tagged and received a curative treatment of diminazene aceturate (Berenil®, Hoechst) by intramuscular injection at a dose of 7.0 mg/kg. Each month, blood taken from the jugular vein of each sentinel animal was examined for trypanosomes using the haematocrit centrifuge and phase contrast microscopy technique (Murray *et al*., 1977) and its packed cell volume (PCV) was measured. Blood smears stained with Giemsa were also examined for the presence of trypanosomes. Infected animals were cured by intramuscular injection of diminazene aceturate at the dose of 7 mg/kg for *Trypanosoma brucei* or 3.5 mg/kg for *T.congolense* or *T.vivax*. The incidence of trypanosomosis was calculated and presented as an average incidence at the various distances (0, 5 and 10 km) from the tsetse re-invasion front.

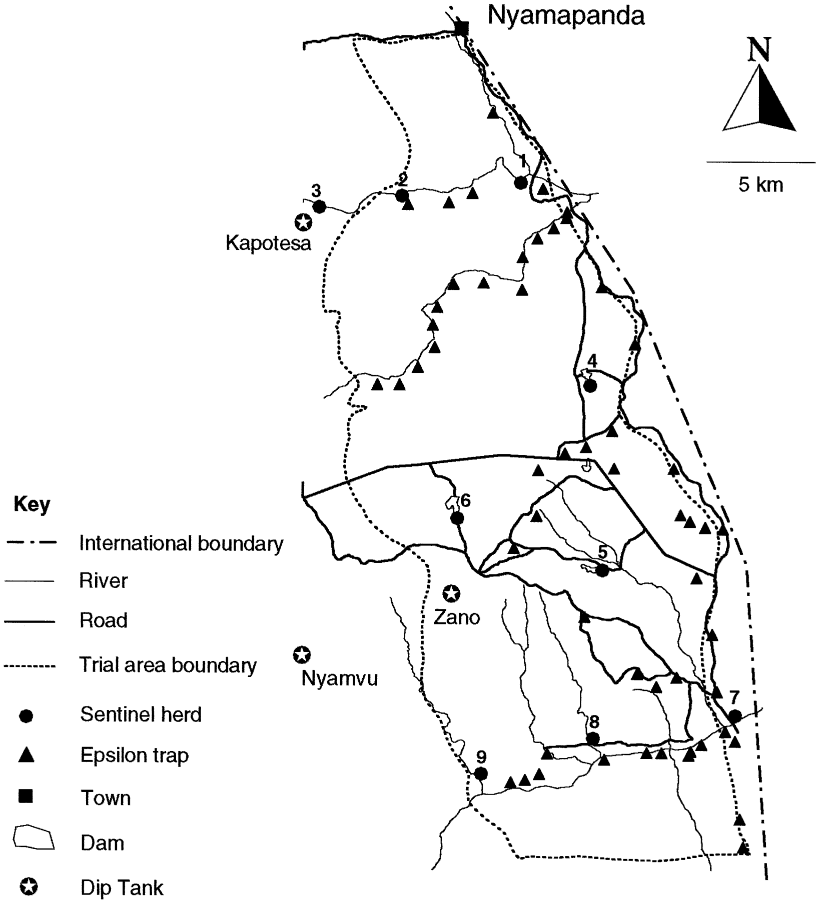

Fig. 1. Trial area in north-eastern Zimbabwe along the border with Mozambique. Targets were placed in transects from left to right every 0.5 km. Additional targets were placed in transects along all the rivers and roads shown on the map, giving a density of 5.4 targets per km^2.

Approximate grazing areas for the local cattle attending the three inspection sites were 0–15 km, 10–18 km and 20–25 km west of the tsetse re-invasion front for Zano, Kapotesa and Nyamvu, respectively. The prevalence of trypanosomosis in these cattle was determined at regular intervals by taking a cross-sectional sample of the adult cattle population at each inspection site. The sample sizes were calculated according to Cannon & Roe (1982) and sampling was conducted as for the sentinel cattle, described above.

Experimental design

The target barrier was maintained for eight months until September 1996 when the targets were removed, leaving only the insecticide treatment of the local cattle to stem the tsetse re-invasion. It was planned to leave the targets out for 12 months, in order to allow for any seasonal changes in tsetse numbers, but, in March 1997 the prevalence of trypanosomal infections in local cattle became unacceptably high and the target barrier was re-deployed in the following month. Tsetse populations and trypanosomiasis in the sentinel herds continued to be monitored for a further 5 months.

Results

Tsetse catch

G.pallidipes accounted for 73% of the catch at the Epsilon traps, but only 3.5% of the catch on ox-fly rounds throughout the trial period. For the analysis, the results from both species were grouped, but the Epsilon trap catches (Table 2) were predominately *G.pallidipes* whereas the ox-fly round catches (Table 1) were predominantly *G.m.morsitans*, reflecting the known sampling biases of these two sampling systems (Hargrove, 1996).

In both cases the removal of the target barrier in September 1996 caused an increase in the catch along the re-invasion front, and a change in the distribution of the catch as the flies moved into the trial area. The positions of all ox-fly round catches throughout the experiment are

Table 1. Total catch of tsetse from 450 to 500 km of ox-fly round covering the trial area each month, with distance from the re-invasion front.

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

Fig. 2. Position of ox-fly round catches in the trial area; (a) before removal of targets (total distance covered 1335 km); (b) after removal of targets (total distance covered 3584 km); and (c) after the targets have been re-deployed. (total distance covered 2296 km).

plotted in Fig. 2. Prior to the removal of the target barrier, catches were confined to an area 10–15 km long, and stretching 2–3 km into the target barrier (Fig. 2a). Once the target barrier was removed, the flies quickly moved into the trial block (Fig. 2b, Tables 1 and 2) and the fly front, or the area where re-invasion occurred, expanded. When the targets were re-deployed in April 1997, the catch dropped and the position of capture immediately reverted to the distribution that was seen before the removal of the targets (Fig. 2c). We were unable to control for seasonal changes in tsetse numbers and their availability at capturing devices, due to the high prevalence of trypanosomiasis in the local stock in March 1997 (Table 3) which caused an early termination of the trial. However, the pattern of tsetse capture does not follow that which is usually observed due to seasonal changes in Zimbabwe (Phelps & Vale, 1978), suggesting that the expanding population from September through to March was a direct result of the removal of the

Table 2. Catch per trap per day in the trial area, with distance from the re-invasion front. The number of trap days was variable due to trap theft, vandalism, or weather damage.

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

Table 3. Point % prevalence of trypanosomiasis in local stock.

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

target barrier. By implication also, the crash in tsetse catch and the immediate restriction in tsetse distribution after the targets were replaced in April 1997, suggests that this was a direct result of the increased mortality imposed on tsetse populations by the targets.

Trypanosomiasis

Prior to the removal of the target barrier, trypanosomal infections were only diagnosed in sentinel cattle grazing along the tsetse re-invasion front (Fig. 3a). During this period (February 1996 – August 1996) the monthly average incidence for the three sentinel herds (1, 4 and 7; Fig. 1) varied from 33.7% in April 1996 to 0% in July 1996 (Fig. 3a). After the removal of the target barrier, the monthly average incidence rose steadily in these herds, reaching a peak of 38.4% the following April. The herds grazing ≈5 km from the re-invasion front (2, 5 and 8: Fig. 1), first showed positive to a trypanosomal infection in November 1996, 2 months after the removal of the target barrier. The trypanosomiasis incidence reached 33.3% in December 1996, and remained high until after the targets were replaced the following April (Fig. 3b).

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

For seven of the 10 months of the trial period during which targets were present, the monthly average PCVs of sentinel herds grazing along the tsetse re-invasion front were significantly lower (*t*-test, $P < 0.05$) than the monthly average PCVs of sentinel cattle grazing either 5 or 10 km from the re-invasion front. The monthly average PCVs of

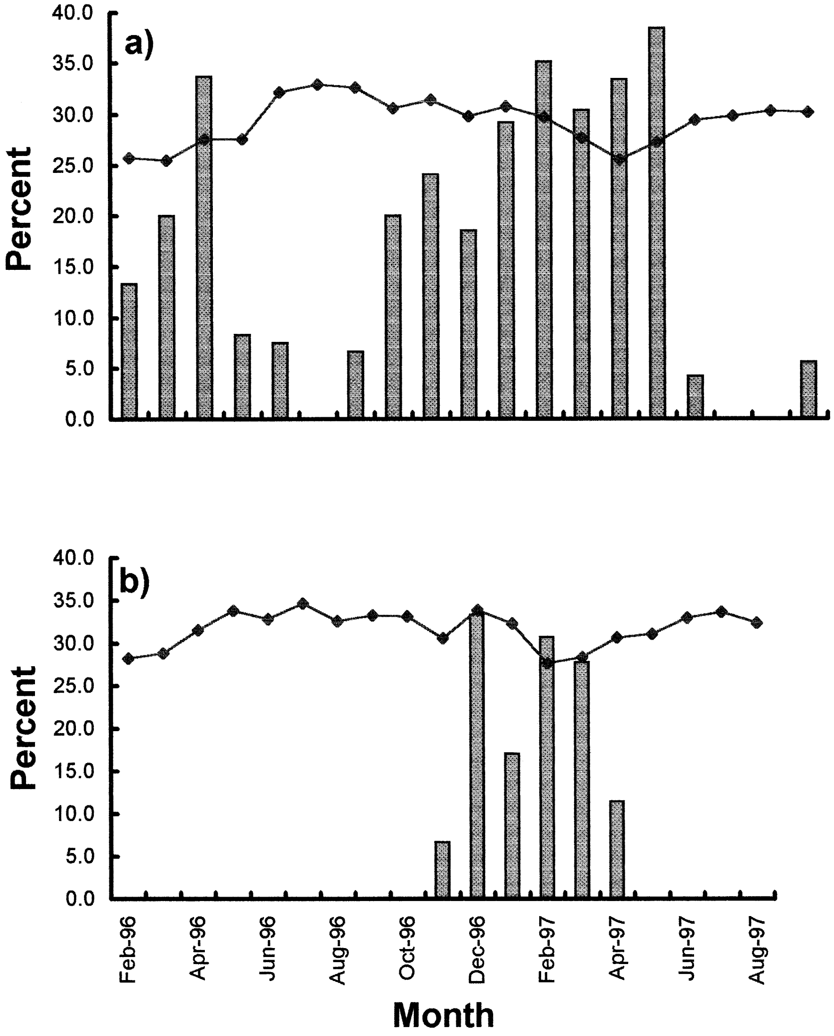

Fig. 3. Incidence of trypanosomiasis in sentinel cattle grazed (a) on or very close to the tsetse re-invasion front (herds 1, 4 and 7 Fig. 1), and (b) 5 km west from the tsetse re-invasion front (herds 2, 5 and 8 Fig. 1). Bars show a monthly incidence and triangles show mean monthly PCV.

sentinel herds at the tsetse invasion front were highly correlated ($r = -0.90$, $P < 0.01$) with the monthly incidence of trypanosomal infections in those animals and reflect the challenge that animals undergo even in the presence of an odour-baited target barrier.

Removal of the target barrier resulted in a decline in the average PCV of herds grazing 5 km from the tsetse re-invasion front (Fig. 3b) but it did not affect the PCVs of cattle grazing 10 km away. Between January 1997 and April 1997, the average PCVs of sentinel herds grazing 5 km west of the invasion front were not significantly different from those of sentinel herds at the re-invasion front. The re-deployment of targets resulted in an immediate increase in the average PCVs of sentinel herds 5 km west of the invasion front (Fig. 3b).

The prevalence of trypanosomal infections in the local cattle population at each of the three inspection sites was greatly increased by removal of the target barrier (Table 3).

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

Discussion

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

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

Previous studies on the effects of insecticide-treated cattle for tsetse control have given mixed but promising results. Bauer *et al.* (1995), working in Burkina Faso, reported good control of tsetse and trypanosomiasis in stock using deltamethrin pour-on, and Fox *et al.* (1993) in Tanzania reported reduced tsetse populations and increased herd health after the deltamethrin treatment of cattle on a large commercial ranch. Baylis & Stevenson (1998), reporting on a trial on the Galana ranch in south-east Kenya, concluded that the effect on herd health was greater than could be expected from the minimal effects on tsetse density caused by cattle treatments. In all of these cases the effect of cattle treatment on tsetse populations and trypanosomiasis *control* was investigated. This is different from our investigation, which was designed to see if treated cattle can prevent tsetse *invasion*. Clearly the answer to this last question, under these circumstances, is **no**.

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

We were unable to test the efficacy of the target barrier in the absence of insecticide-treated cattle. However, the level of management of the target barrier was high and resources were not a limiting factor. Due to the logistical difficulties involved in maintaining a target barrier, and variable resource inputs, it is probably wise to continue insecticidal dipping of cattle in the barrier, to cover for possible breakdowns in barrier efficacy. The additional cost of using a deltamethrin-based dip rather than the routinely used acaricide is low compared to the cost of mopping up tsetse populations that become established through a poorly maintained target barrier.

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References

Bauer, B., Amsler-Delafosse, S., Clausen, P.-H., Kabore, I. & Petrich-Bauer, J. (1995) Successful application of deltamethrin pour on to cattle in a campaign against tsetse flies (*Glossina* spp.) in the pastoral zone of Samorogouan, Burkina Faso. *Tropical Medicine and Parasitology*, **46**, 183–188.

Bauer, B., Kabore, I., Liebisch, A., Meyer, F. & Petrich-Bauer, J. (1992) Simultaneous control of ticks and tsetse flies in Satiri, Bukino Faso, by the use of flumethrin pour on for cattle. *Tropical Medicine and Parasitology*, **43**, 41–46.

Baylis, M., Mbwabi, A.L. & Stevenson, P. (1994) The feeding success of tsetse flies, *Glossina pallidipes* (Diptera: Glossindae), on oxen treated with pyrethroid pour-ons at Galana Ranch, Kenya. *Bulletin of Entomological Research*, **84**, 447–452.

Baylis, M. & Stevenson, P. (1998) Trypanosomiasis and tsetse control with insecticidal pour-ons: fact and fiction? *Parasitology Today*, **14**, 77–82.

Cannon, R.M. & Roe, R.T. (1982) Livestock disease surveys. *A Field Manual for Veterinarians*, pp. 1–26. Australian Government Publishing Service, Canberra.

Fox, R.G.R., Mmbando, S.O., Fox, M.S. & Wilson, A. (1993) Effect on herd health and productivity of controlling tsetse and trypanosomiasis by applying deltamethrin to cattle. *Tropical Animal Health and Production*, **25**, 203–214.

Hargrove, J.W. (1993) Target barriers for tsetse flies (*Glossina* spp.) (Diptera: Glossinidae): quick estimates of optimal target densities and barrier widths. *Bulletin of Entomological Research*, **83**, 197–200.

Hargrove, J.W. (1996) Factors affecting the probability of host and trap location by tsetse flies (*Glossina* spp.) on an island in Zimbabwe. (Abstracts of the XX International Congress of Entomology).

Hargrove, J.W. & Langley, P.A. (1990) Sterilizing tsetse (Diptera, Glossinidae) in the field – a successful trial. *Bulletin of Entomological Research*, **80**, 397–403.

Murray, M., Murray, P.K. & McIntyre, W.I.M. (1977) An improved parasitological technique for the diagnosis of African trypanosomosis. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, **71**, 325–326,.

Phelps, R.J. & Vale, G.A. (1978) Studies on populations of *Glossina morsitans morsitans* and *G. palldipes* in Rhodesia. *Journal of Applied Ecology*, **15**, 743–760.

Scoones, I. (1995) Exploiting heterogeneity: habitat use by cattle in dryland Zimbabwe. *Journal of Arid Environments*, **29**, 221–237.

Shereni, W. (1990) Strategic and tactical developments in tsetse control in Zimbabwe (1981–89). *Insect Science and its Application*, **11**, 399–409.

Torr, S.J., Hall, D.R., Phelps, R.J. & Vale, G.A. (1997) Methods for dispensing odour attractants for tsetse flies (Diptera: Glossinidae). *Bulletin of Entomological Research*, **87**, 299–311.

TTCB (1992) *Annual Report of the Tsetse and Trypanosomiasis Control Branch*, Department of Veterinary Services, Zimbabwe.

Vale, G.A., Lovemore, D.F., Flint, S. & Cockbill, G.F. (1988) Odour-baited targets to control tsetse flies, *Glossina* spp. (Diptera: Glossinidae), in Zimbabwe. *Bulletin of Entomological Research*, **78**, 31–49.

Van den Bossche, P. & Duchateau, L. (1998) The effect of deltamethrin pour-on treatments on the incidence of tsetse-transmitted trypanosomosis. *Revue d'Elevage et de Medecine Veterinaire Des Pays Tropicaux*, **51**, 123–126.

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