UNICEF/UNDP/WorldBank/WHO
Special Programme for Research and Training in Tropical Diseases (TDR)

STRATEGIC REVIEW OF TRAPS AND TARGETS FOR TSETSE AND AFRICAN TRYPANOSOMIASIS CONTROL

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STRATEGIC REVIEW OF TRAPS AND TARGETS FOR TSETSE AND AFRICAN TRYPANOSOMIASIS CONTROL

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TABLE OF CONTENTS

ABBREVIATIONS

AU	African Union (formerly OAU)
CATT	Card agglutination test for trypanosomiasis
CFA	Franc de la Communauté Financière d'Afrique (the currency of several West African countries)
DALY	Disability adjusted life years (a measure of the social impact of a disease)
DNA	Deoxyribonucleic acid
DFID-AHP	Department for International Development, Animal Health Programme, UK
FITCA	Farming in Tsetse Controlled Areas (a series of EC funded development projects in Africa)
ECLAT	the European Community – Latin American Network for research on the biology and control of Triatominae
FAC	Fonds d'Aide et de Coopération Français
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic information system
GPS	Global positioning sensor/system
HAT	Human African trypanosomiasis
IAEA	International Atomic Energy Agency
IFAD	International Fund for Agricultural Development
ISCTRC	International Scientific Council for Trypanosomiasis Research and Control
OAU	Organization for African Unity
OCCGE	Organisation de Coordination et de Coopération pour la lutte contre les Grandes Endémies
OPEC	Organization of Petroleum Exporting Countries
ORSTOM (now **IRD**)	Institut de Recherche pour le Développement
PAAT	Programme Against African Trypanosomiasis
PATTEC	Pan African Tsetse and Trypanosomiasis Eradication Campaign
PATTEC-PMC	PATTEC Policy and Mobilisation Committee
RTTCP	Regional Tsetse and Trypanosomiasis Control Programme for Southern Africa
SAT	Sequential aerial technique
SIT	Sterile insect technique
TDR	UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases
UCLT	Unité Centrale de Lutte contre les Tsetse et les trypanosomoses animales
ULV	Ultra low volume
WHO	World Health Organization

EXECUTIVE SUMMARY

- Tsetse traps and targets (insecticide-impregnated screens) function by attracting the flies to a device that collects and/or kills them. Traps can be used for entomological surveillance, and also for control. Targets are simpler than traps, but are not used for surveillance. They are impregnated with biodegradable insecticides in order to kill any flies that alight on them. Traps can also be impregnated with insecticides. Traps and targets can both be used to eliminate a fraction of the tsetse population.

- Various designs of trap and target have been developed for use against particular target species in particular environments. They differ in cost and maintenance requirements, and are not equally effective for all species. However, for the most significant target species and groups, an adequate and field-tested design is available.

- Basic traps and targets function through visual stimuli. Their effectiveness can be greatly enhanced through the use of odour baits. However, satisfactory odour baits are not readily available for all species, so that further work on odour baits is warranted.

- The effectiveness of traps and targets as control tools depends on their rate of removal of flies from the existing population. Evidence from field studies and theoretical work indicates a linear relationship between tsetse density and the likelihood of trypanosomiasis transmission. Trap and/or target deployment can therefore be recommended as a component of measures to control and prevent trypanosomiasis epidemics.

- In terms of tsetse population density, the transmission threshold for human trypanosomiasis seems generally much higher than that for animal trypanosomiasis, implying that transmission of human trypanosomiasis is more readily halted by reducing tsetse density. This indicates that trap and/or target deployment would be a useful adjunct to case detection and treatment in any focus of active transmission. It is possible that some current foci of human trypanosomiasis – especially gambiense – might be quickly eliminated by a combination of these two approaches, even without eliminating the local tsetse population.

- There are clear practical difficulties in the long-term deployment of traps and/or targets, mainly related to physical degradation, damage by wind or large animals, and theft. Traps and targets cannot be maintained indefinitely by local communities; a minimum degree of technical support is required. But community interest wanes if trap/target deployment reduces the perception of tsetse as a problem. Farming communities may show greater appreciation of traps than targets since they can see the captured flies, recognize that nuisance flies are also controlled to some extent, and see a clear benefit to their cattle (including reduced outlay on cattle trypanocides).

- Traps and targets are a key component of large-scale interventions against tsetse, including the use of traps for surveillance. Current approaches envisage large-scale but relatively short-term deployment of traps and targets (in some cases combined with other methods such as aerial spraying and/or live baits) to reduce tsetse populations to levels at which local elimination can be achieved, followed by progressive extension of treated areas to eliminate the panmictic population.

- The expressed priority of African governments calls for elimination of the tsetse and trypanosomiasis problem "in the shortest time possible". The proposed strategy of the African Union, through the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) initiative, calls for large-scale deployment of traps and targets in conjunction with other methods, but will require further studies on tsetse movement – probably using population genetic analysis as a surrogate for dispersal – in order to optimize trap and target placement in relation to definably panmictic populations.

1. BACKGROUND AND CONTEXT

The TDR Steering Committee on Implementation Research recommended a strategic review of the use of traps and targets for tsetse and trypanosomiasis control. Such a recommendation is timely in view of increasing concerns about the rise in case incidence of African trypanosomiasis – especially in areas of Angola and the Democratic Republic of the Congo (DRC) – and also in view of the recently launched Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) initiative through which the heads of state and government of 36 African countries declared, as priority, the need to *"...act collectively and rise to the challenge of eradicating tsetse flies from the African continent in the shortest time possible"* (OAU summit Lomé, July 2000, Decision AHG/Dec.156/XXXVI). The PATTEC Plan of Action was endorsed at the Organization of African Unity (OAU) summit in Lusaka, July 2001 (Decision AHG/Dec.169/XXXVII), and at the African Union (AU)/OAU summit in Durban, July 2002 (OAU/AU Decision CM/Dec.661/LXXVI) (see Kabayo, 2002). The PATTEC initiative has also been endorsed by general conference resolutions of the Food and Agriculture Organization (FAO)[1] and the International Atomic Energy Agency (IAEA)[2], and by a resolution of the World Health Assembly[3].

PATTEC is now formally integrated into the AU (formerly OAU), with a permanent secretariat under the AU Commissioner for Rural Development. Its plan of action runs in parallel and complementary to the WHO initiative for sleeping sickness diagnosis and treatment, and focuses on progressive elimination of discrete areas of tsetse populations using a combination of methods depending on fly species, terrain and habitat, and local and national experience. In general terms, the technical approach is expected to involve the use of traps, targets, and/or sequential ultra-low-volume (ULV) aerial spraying (SAT) to reduce tsetse populations to very low levels, followed if necessary by sterile insect release (SIT) to eliminate any last remaining flies. A pilot programme to test the principle of this approach was successfully implemented in Zanzibar (1994-1997), from where *Glossina austeni* now seems to have been completely eliminated (Vreysen et al., 2000). More recently, a similar approach was applied in the Okavango delta region of Botswana, and no tsetse have since (in the last 12 months) been encountered. Through PATTEC, this programme is now being extended into western Zambia and through the Caprivi strip of Namibia into southern Angola.

Traps and targets are seen as a key component of efforts to control and eliminate tsetse, and for maintaining temporary barriers between treated and untreated regions to prevent tsetse reinvasion. Importantly, traps are also seen to be a key factor in monitoring the progress of interventions, and in reaching decisions about implementation of SAT or SIT. Moreover, at the community level, traps and targets can be deployed to suppress tsetse populations in areas of sleeping sickness outbreaks; however, costs and logistics may be important impediments.

This review seeks to assess the history and design of tsetse traps and targets deployed in specific situations, and their operational and economic implications as well as apparent effectiveness in relation to both community and farm protection. The review focuses on measures to combat human trypanosomiasis (sleeping sickness), but draws on experience from the control of animal trypanosomiasis wherever relevant.

[1] FAO 31st General Conference, Resolution No. 4/2001

[2] IAEA 45th General Conference Resolution GC(45)/RES/12
IAEA 46th General Conference Resolution GC(46)/RES/11

[3] 56th World Health Assembly Resolution WHA56.7, 2003

2. INTRODUCTION: AFRICAN TRYPANOSOMIASIS AND ITS CONTROL

Trypanosomes transmitted by tsetse flies represent a severe constraint to health and development in much of sub-Saharan Africa. The human-infective forms are subspecies of *Trypanosoma brucei;* they give rise to a condition known as sleeping sickness or human African trypanosomiasis (HAT). Three subspecies of this parasite are recognized (Hoare, 1972): *T. b. brucei* infects cattle and other large mammals but is not known to infect humans; *T. b. rhodesiense* infects humans and mammals; *T. b. gambiense* infects humans but has less commonly been isolated from animals. These subspecies are morphologically indistinguishable; the main difference between them is the ability of the human infective forms – gambiense and rhodesiense – to survive incubation with human blood or plasma, whereas *T. b. brucei* succumbs to 'trypanosome lytic factors' associated with high density lipoproteins in human blood (Jenni & Brun, 1982; Rickman & Robson, 1970; Hager & Hajduk, 1997). Human infection with *T. b. rhodesiense* – mainly found in parts of eastern and southern Africa – usually leads to an acute disease (rhodesiense sleeping sickness), whereas infection with *T. b. gambiense* – common in western and central Africa – tends to lead to a more chronic infection (gambiense sleeping sickness). The principal signs and symptoms of HAT are intermittent fever with enlarged lymph glands and spleen in the early stage, followed in the advanced or late stage by neurological symptoms and endocrine disorders. Both forms of HAT can be fatal if untreated – usually due to meningoencephalitis following entry of the parasites into the central nervous system.

At present, WHO estimates suggest around 500 000 new cases of sleeping sickness each year, with about 60 million people considered at risk (WHO, 1998; Jannin J, unpublished, 2004). The number of cases officially reported to WHO is much lower, but reveals a steady rise since the 1960s (Fig. 1), with several epidemics, especially in areas of conflict such as southern Sudan (1970 – ongoing), Uganda (1977-95), Angola (1980 – ongoing), and most recently in Chad and the DRC (formerly Zaire). Recent estimates are that there were 1.53 million disability adjusted life years (DALYs) lost due to HAT in 2002, and 48 000 deaths (WHO, 2004).

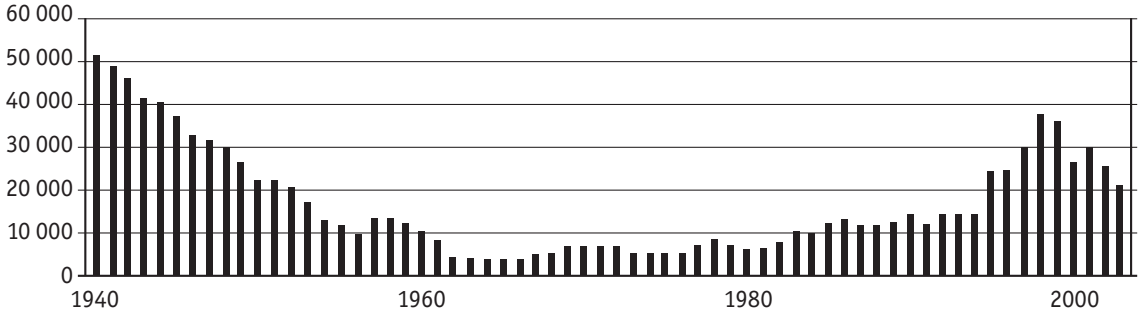

Fig. 1 Number of reported cases of sleeping sickness in Africa, 1940-2002
(from data kindly provided by Guillaneux S, Bauquerez R, and Jannin J, WHO, Geneva)

T. brucei is one of several trypanosomes that can infect cattle and other livestock in Africa. Other widespread species include *T. congolense* and *T. vivax* of bovids, equines and small ruminants, and *T. simiae* of pigs. These are transmitted cyclically by tsetse flies (Diptera, Glossinidae) in the sense that the trypanosomes undergo development in the tsetse vectors, although *T. vivax* and *T. simiae* can also be transmitted mechanically by horseflies (Diptera, Tabanidae) and other bloodsucking insects, and are thus recorded from regions outside the tsetse-infested areas of Africa. *T. evansi,* which mainly infects camels, horses and dogs, is transmitted by horseflies but not tsetse and so also occurs outside the tsetse infested zones of Africa. In terms of pathology in livestock, the tsetse-transmitted trypanosomes can be grouped as haematic *(congolense, vivax, simiae)* or humoral (*brucei* forms)

(Losos & Ikede, 1972). The diseases caused by the haematic group are largely due to anaemia, whereas although anaemia also occurs with *brucei* infection, the pathology is often more associated with tissue degeneration and inflammation. In horses and small ruminants (sheep and goats), infection with *T. brucei* may also cause central nervous symptoms including staggering and paralysis. The severe wasting disease of cattle, particularly associated with *congolense* infection, is often known as nagana (from a Zulu word meaning 'to be in low or depressed spirit'), although this term is also applied generally to trypanosome infections of livestock. The word 'tsetse' is believed to originate from the Tswana language in Botswana, meaning 'fly that kills livestock'.

Tsetse occur over much of sub-Saharan Africa, in an area approaching 10 million km^2 (see Fig. 2 on page 33). The trypanosomes they transmit affect human health, both directly through the gambiense and rhodesiense forms of sleeping sickness, and indirectly through the wasting diseases of livestock. The effect on livestock not only reduces the availability of meat and dairy produce, but most particularly denies the use of cattle and horses for transport and traction. For agricultural communities, this means that only small areas can be tilled by hand, leaving the communities vulnerable to food shortages, starvation, and famine. For example, studies by Govereh (1999) indicate that if draught animals were available, a family currently dependent on manual labour alone could increase its income from agricultural work by 45% per unit of land, and 143% per unit of labour (FAO, 2000). From initial estimates by Steelman (1976), FAO (1994) estimated that for the whole of Africa, overall agricultural losses attributable to trypanosomiasis would total more than US$ 4 billion annually – a figure independently corroborated by Budd (1999), who estimated that agricultural benefits accruing to tsetse elimination could reach US$ 4.5 billion per year. Tsetse have been termed 'the poverty insects' in WHO/FAO communiqués.

2.1 EPIDEMIOLOGY OF AFRICAN TRYPANOSOMIASIS

2.1.1 Transmission

Adult tsetse – male and female – feed exclusively on vertebrate blood; the immature stages do not feed. Adult flies can become infected with trypanosomes by taking a bloodmeal from an infected host. Once the infection is established, the flies appear to remain infected for life. However, cyclical development - the establishment and development of the trypanosomes in the tsetse vectors - is a complex process, involving a series of vector and parasite defence and counter-defence mechanisms (Wellburn & Maudlin, 1999), and there is evidence that tsetse become harder to infect as they mature. Often therefore, natural populations of tsetse show relatively low infection rates – generally less than 0.1% in the case of human-infective forms, but often as high as 10-15% in the case of cattle – infective forms.

Under current classifications, the 31 currently recognized species and subspecies of *Glossina* are customarily placed into three species groups which are sometimes given subgeneric status (Haeselbarth, Segerman & Zumpt, 1966): fusca group (subgenus *Austenina*), palpalis group (subgenus *Nemorhina*), and morsitans group (subgenus *Glossina*) (Table 1). These groupings are based primarily on morphological features of the adult genitalia (Newstead, Evans & Potts, 1924) although they also reflect differences in distribution, habitat and behaviour (Jordan, 1993). Species of the fusca group typically occur in lowland rain forests of West and Central Africa (exceptions being *G. longipennis* and *G. brevipalpis* in the drier regions of eastern Africa); species of the palpalis group are more usually associated with riverine vegetation, but some also extend into savannah regions between river systems; while species of the morsitans group are primarily associated with drier savannahs. These groupings can also be demonstrated by comparative gene sequence analysis and by geometric wing morphometry (Patterson & Schofield, 2004), and also coincide broadly with epidemiological significance. It is believed (although not demonstrated in every case) that all species and

TABLE 1. SPECIES GROUPS OF GLOSSINA

FUSCA group (mainly forest areas of West and Central Africa, except *longipennis* that occupies dry areas of East Africa)

G. fusca fusca
G. fusca congolensis
G. nigrofusca nigrofusca
G. nigrofusca hopkinsi
G. tabaniformis
G. medicorum
G. hanningtoni
G. fuscipleuris
G. nashi
G. schwetzi
G. frezili
G. severini
G. vanhoofi
G. longipennis
G. brevipalpis

PALPALIS group (mainly riverine and lakeshore habitats)

G. palpalis palpalis	TBG
G. palpalis gambiensis	TBG
G. tachinoides	TBG (some TBR)
G. pallicera pallicera	
G. pallicera newsteadi	
G. caliginea	
G. fuscipes fuscipes	TBG
G. fuscipes quanzenis	TBG
G. fuscipes martinii	TBG (some TBR)

MORSITANS group (mainly savanna areas, including open woodland and thickets)

G. morsitans morsitans	TBR
G. morsitans submorsitans	TBR
G. morsitans centralis	TBR
G. austeni	
G. longipalpis	
G. pallidipes	TBR
G. swynnertoni	TBR

TBG – important vector of *T. b. gambiense*
TBR – important vector of *T. b. rhodesiense*

subspecies of tsetse are potential vectors of trypanosomes; animal trypanosomiasis can essentially be found wherever wild tsetse populations are present. However, human trypanosomiasis has a much more focal distribution, usually – but not exclusively – associated with so-called 'historic foci' of disease, and with strong epidemic potential (De Raadt, 1999). Most *T. b. gambiense* transmission is attributed to species of the palpalis group occupying riverine and forest habitats in West and Central Africa, while most *T. b. rhodesiense* transmission is attributed to species of the morsitans group in savannah-like areas of East Africa. Species of the fusca group, although important as vectors of animal trypanosomiasis, are generally considered insignificant as vectors of the human-infective forms.

The main reservoir host of *T. b. gambiense* seems to be humans, although the parasite has also been found in other animals, particularly pigs but also dogs, sheep and some wild ruminants (Gibson, 1986). There is genetic evidence to suggest the existence of at least two forms of *T. b. gambiense* (Tait, Babiker & Le Ray, 1984); the group I form seems less variable and most typically associated with chronic gambiense infection, while the group II form is more variable and may be associated with a more acute disease (Gibson, 1986). The importance of non-human reservoirs in maintaining these forms of gambiense is not entirely clear, and it was thought that extensive case detection and effective treatment could be sufficient to eliminate the human infection (see WHO, 2001). However, as Rogers (1988) has shown, if there were no non-human reservoirs, then *T. b. gambiense* would probably have died out in West Africa, especially recalling the extensive control efforts carried out during the earlier part of the 20th century. Thus, elimination of transmission from non-human reservoirs to humans will probably be required, in addition to case detection and treatment, in order to eliminate existing foci of the disease.

In contrast to gambiense, *T. b. rhodesiense* is found extensively in cattle, and also in a range of wild and domestic mammals – including bushbuck, reedbuck, lion, giraffe, hyaena and hippopotamus. It occurs usually as a mixed infection with *T. b. brucei* such that the two forms are primarily distinguished by the presence of the serum resistance associated (SRA) gene in *T. b. rhodesiense*, which confers the ability to resist serum lysis in the human host (Gibson, 2002; Gibson, Backhouse & Griffiths, 2002; Njiru et al., 2004). It may be that rhodesiense is a relatively simple genetic derivative of brucei (see Hager & Hajduk, 1997), and there is evidence that it has derived several times (Gibson, 2002). In operational terms, this implies that human case detection and treatment would be, alone, insufficient to halt transmission. Thus, although case detection and treatment of human cases is important for the control of both gambiense and rhodesiense infections, control of the rhodesiense form is particularly reliant on other methods to halt transmission – particularly through elimination of the local tsetse vectors.

2.1.2 Historical aspects

The earliest report of human sleeping sickness is attributed to Arabic historians describing the death of King Diata II, Sultan of Mali, in 1373 (De Raadt, 1999), while nagana of cattle has been known since the 15th century (Nash, 1969). However, it is generally held that African trypanosomiasis was of relatively minor significance prior to European invasion of the continent. Spread of the disease coincided with the opening up of the continent by European colonial rule at the end of the 19th century, which brought about improved communication and increased contact between communities hitherto isolated. European explorers of the interior of Africa quickly encountered difficulties due to the human disease, but most particularly with the animal disease as this restricted the use of oxen and horses for transport. This was also a serious problem for the allied armies in Africa during World War I (Ford, 1971).

By the end of the 19th century, the colonial authorities in Africa had become seriously concerned about the trypanosomiasis problem, both as a problem for livestock and as a human disease. There

were serious epidemic outbreaks in several regions, particularly in the Congo basin (especially northern Angola) and around the Lake Victoria basin. For this epidemic period (1895-1910), the total number of deaths due to trypanosomiasis in the Congo basin was estimated at 500 000, and in the Lake Victoria region at around 250 000 (Mulligan, 1970). Following a series of scientific commissions, the causative agents and their tsetse vectors were recognized, and a series of measures were adopted for control. These included development and use of the first arsenical compounds to treat the disease, combined with resettlement of exposed communities, and extreme measures to reduce tsetse populations including attempts to eliminate wild game animals as hosts of tsetse and trypanosomes, and extensive bush clearance to eliminate tsetse resting sites. Through the early part of the 20th century, these measures had considerable effect; they were progressively improved through the introduction of more effective diagnosis and treatment regimes, sticky traps to catch tsetse, and, by 1950, large-scale application of synthetic insecticides.

By the 1960s, tsetse and trypanosomiasis research and control services were well established throughout most of the endemic regions of Africa. Cases of human sleeping sickness declined to an estimated level of no more than 15 000-25 000 per year for the whole continent (prevalence rates of <0.1% in many endemic countries). Worldwide interest in the trypanosomiases declined, and a combination of post-independence events contributed to a progressive reduction of activities in tsetse and trypanosomiasis control throughout much of Africa. Since then, human and animal trypanosomiasis has steadily resurged, even in areas where it had previously been well controlled (Fig. 1). To a very large extent, subsequent outbreaks of human trypanosomiasis can be associated with wars and civil unrest, as seen by the epidemics of human sleeping sickness in Sudan (1970–ongoing), Uganda (1977-95), Angola (1980-ongoing), and most recently in the DRC (Abel et al., 2004; Stich, Barrett & Krishna, 2003; WHO, 2001). Any historical review might reasonably predict that current and future regions of conflict could also lead to additional outbreaks of human sleeping sickness, unless pre-emptive measures are taken.

2.1.3 Diagnosis and treatment

Diagnosis and treatment of human trypanosomiasis is by no means an easy task, even without the logistical and infrastructural difficulties of patient access in remote rural areas. In the early haemolymphatic stage, there are no specific symptoms and the infection is readily confused with other febrile illnesses, especially malaria. The later stage of infection (meningo-encephalitic stage) is easier to diagnose but can have irreversible consequences and requires treatment with drugs with adverse side-effects (WHO, 1998; TDR, 2003; Fairlamb, 2003). The available drugs are: for early-stage sleeping sickness, pentamidine for gambiense infection and suramin for rhodesiense infection; and, for late-stage sleeping sickness, melarsoprol for both gambiense and rhodesiense infection, and eflornithine for gambiense infection. Diagnosis of the disease currently relies on parasitological examination of blood using various concentration techniques and serological tests such as the card agglutination trypanosomiasis test (CATT). Determination of the stage of disease must be made by parasitological and biological examination of cerebrospinal fluid (CSF) obtained by lumbar puncture. The latter is particularly important for determining both treatment regime and prognosis. Through partnerships between Aventis, Bayer, and WHO, all drugs used in the treatment of human African trypanosomiasis are now available free of charge through WHO Geneva. For many endemic countries however, the diagnostic infrastructure has yet to be developed, and there are problems of serious adverse side-effects and/or drug resistance with some of the available treatments.

2.2 TSETSE BIOLOGY

Tsetse are unique amongst medically important vectors, with a series of biological and demographic characteristics that make them very vulnerable to available control techniques. Their life cycle is particularly unusual since they do not lay eggs. Instead, an inseminated female develops the egg and young larva within her uterus, laying the mature (3rd instar) larva into shaded soil. The larva quickly burrows under the soil surface and pupates, and the adult emerges 20-45 days later depending on temperature (pupal development does not succeed below 17°C and above 32°C). Thus, each female produces only one offspring at a time, and can produce up to 12 offspring – at intervals of about 9-10 days – during her typical adult lifespan of 2-3 months. As a result, the intrinsic rate of tsetse population growth tends to be low, with the maximum rate of population increase estimated to be no more than 10-15 times per year (Rogers, 1979[a]; Hargrove, 1988). This means that even small increases in average daily mortality rate can cause a population to decline in number – even to extinction. Simulations of *G. pallidipes* and *G. m. morsitans*, for example, suggest that daily elimination of even 1% of a population could provide effective control (Vale, Bursell & Hargrove, 1985), while sustained elimination of 2-4% would generally lead to population extinction (Hargrove, 1988, 2003[a],[b]).

Since tsetse larvae do not feed, but are nourished by the uterine glands of the mother, the entire nutritional intake of the flies is limited to vertebrate blood. Newly emerging flies have few resources, and tend to be less discriminatory about the host for their first bloodmeal than for subsequent feeds. For flight, adult tsetse rely on partial metabolism of proline, an amino acid derived from the bloodmeal, and when this is exhausted they must rest in order to reconstitute the limited proline reserve. One result is that tsetse are generally unable to fly for long periods, flying instead in short bursts, with a relatively low capacity for active dispersal. *G. morsitans* has been observed to fly at speeds of up to 4 metres/second (m/s) on laboratory flight mills (Hargrove, 1975), although mean speeds of about 6 m/s and maximum speeds of 10 m/s have been recorded in the field with video cameras (Gibson & Brady, 1988). Flights in the laboratory generally last for 1 to 2 minutes (Bursell, 1978; Brady, 1988). Brady (1988) showed that bursts of activity last for 30-50 seconds irrespective of the hunger state of the flies, but that the interval between bursts decreases as the flies become hungrier. Bursell & Taylor (1980) also argue that the flying time of tsetse is limited to about 15-30 minutes per day. Thus, if the duration of each flight in the field is typically between 30-60 seconds at an average flight speed of 5 m/s, then each flight will cover between 150 and 300 metres, and the total distance flown per day would be between 4.5 and 9 km. In a random walk model, a step length of 50 m and a total flight distance of 4.5 km give a root-mean-square displacement in one day of 167 m, while a step length of 200 m and a total flight distance of 9 km give a root-mean-square displacement in one day of no more than 1.3 km (Williams, Dransfield & Brightwell, 1992).

A further consequence of the unusual life history of tsetse is their tendency to have low genetic variability within a given population (Gooding, 1984; Krafsur, 2003). This is partly a consequence of low dispersal rate, and partly due to the low reproductive rate, probably combined with selection for the most energetically-efficient individuals. This aspect remains to be fully explored in tsetse (although it is well established for trypanosomiasis vectors in Latin America – see Dujardin et al., 2000), but could explain the low likelihood of selecting for new attributes such as insecticide resistance. Simulation models based on *G. morsitans* show that, even with repeated exposure, selection for insecticide resistance in tsetse would be unlikely (Maudlin, Green & Barlow, 1981). Moreover, operational studies show that tsetse have an exceptional susceptibility to modern pyrethroid insecticides. Control work in the Okavango delta region of Botswana achieved apparent elimination of *G. m. centralis* using sequential aerial spraying of deltamethrin at 20 mg a.i./hectare (Allsop & Phillemon-Motsu, 2002; TIC, 2002), which is more than 10 000 times *less* than the application rate applied against trypanosomiasis vectors in Latin America.

With these attributes – low reproductive rate, low dispersal capacity, and low genetic variability, combined with exceptional susceptibility to available insecticides – tsetse would appear to be highly vulnerable targets for well executed control measures. Indeed, review of the history of past attempts to control tsetse reveals that, without exception, all tsetse control campaigns were successful – until they stopped. But equally, most previous control campaigns against tsetse were of limited geographical coverage, and maintained only during a limited period. So when the control interventions were halted, in most cases the controlled regions were left susceptible to progressive reinvasion by tsetse from neighbouring areas. This exemplifies the need for large-scale 'area-wide' approaches that can reach a sustainable end-point at which, even in the face of declining interest, lack of continued resources, or political upheaval, the biological target is unable to reconstitute the controlled populations (see Schofield, 1991).

2.3 TSETSE CONTROL

A wide variety of tsetse control techniques have been developed and have undergone trial. From this extensive experience, it would seem possible to tailor a package of intervention measures that could give satisfactory control of tsetse within any given target region.

The control techniques include:

Bush and game clearance. Early attempts to control tsetse included extensive bush clearance (designed to eliminate the shaded places where tsetse rest and lay their larvae) and extensive shooting of wild game animals (designed to eliminate the wild blood sources used by the tsetse). Although widely effective, such methods can no longer be recommended.

Insecticides.

- **Ground spraying**. Trials with insecticides against tsetse started in 1945, when DDT and BHC (HCH) were the only synthetic compounds available. The application of residual deposits of persistent insecticides to tsetse resting sites was very widely used, but is now discouraged due to concerns about effects on non-target organisms.

- **Sequential aerial technique (SAT)**. Because of the tsetse fly's exquisite susceptibility to modern insecticides, high levels of tsetse control can be achieved by sequential aerial spraying of ultra low dosages of biodegradable products. Using modern global positioning systems (GPS), SAT can now be applied highly accurately along pre-planned flight lines. In the past, SAT involved the use of using endosulfan, an organophosphate that can no longer be recommended on environmental grounds. More recently, use has been made of pyrethroids such as deltamethrin at doses that are generally too low to provoke significant effects on other fauna (to give an example, the deltamethrin doses applied in recent campaigns against *G. m. centralis* in Botswana were approximately 10 000 times less than those typically applied against Chagas disease vectors in Latin America).

Traps and targets (see pictures pages 26-33). In the early 1900s, sticky traps worn by plantation workers were successfully deployed on the Island of Principe to eradicate *G. palpalis*. Since then, trapping techniques have been greatly enhanced by development of designs that mimic the fly's perception of vertebrate hosts. These generally use blue and black cloth in a shape that attracts the flies and then funnels them upwards into a netting trap – usually in the form of a monoconical (pyramidal) or biconical shape. For tsetse control, a simpler and cheaper device involves a suspended screen of blue and black cloth (often known as a tsetse target) impregnated with a biodegradable pyrethroid insecticide such as deltamethrin. Flies are attracted by the blue segments and land on the black segment, quickly succumbing to the insecticide. The effectiveness of traps and targets can be greatly enhanced by addition of an appropriate odour bait. Such odour baits are usually short-chain aromatic compounds such as acetone or octenol.

Live bait techniques. Similar to the concept of traps and targets, the live bait technique involves treating cattle with appropriate insecticide formulations, usually by means of cattle dips, or as pour-on, spot-on, or spray-on veterinary formulations. These are highly effective against tsetse, and have the additional advantage of controlling other flies and cattle ticks.

Sterile insect technique (SIT). SIT exploits the particular mating biology of tsetse, whereby female flies rarely mate more than once. Male flies are therefore mass reared in the laboratory, sterilized by irradiation, and released to mate with wild females. Females mated with sterile males are unable to produce offspring. Unlike all other tsetse control techniques, SIT has no effect on non-target organisms. Also unlike other techniques, SIT becomes more efficient at lower fly densities, and is ideally suited to the final phase of local tsetse eradication.

3. TRAP AND TARGET DESIGN AND DEPLOYMENT

3.1 THE BASIC PRINCIPLES OF TRAPS AND TARGETS

Since tsetse have a high metabolic rate and feed exclusively on vertebrate blood, their survival depends on detecting and encountering suitable hosts on which to feed. This principle can be exploited in the design of traps and targets which mimic key features of host animals, attracting tsetse in such a way that they are then captured or killed. In the case of traps, the captured flies can be identified and counted, providing an immediate use in sampling the existing tsetse population(s). With targets however, flies pick up a lethal dose of the insecticide by contact with the insecticide-treated surfaces; they may fly away but die later and are then lost, so that targets are of little use in population sampling.

As tsetse control tools, traps and targets function by removing individuals from the existing tsetse population. Their efficiency depends on the length of time the devices remain operational, and the likelihood that an individual fly will encounter the device and be killed by it. The length of time each device remains operational depends on a number of factors including resistance to environmental damage (e.g. wind and/or damage by large animals), theft of all or part of the device, and component degradation (particularly colour fade, depletion of odour baits, and loss of insecticidal activity in the case of targets). The likelihood that an individual fly will encounter and be killed or captured by the device depends also on the number of traps or targets relative to the local abundance of tsetse, and on the particular foraging and dispersal behaviour of the target tsetse species. In the case of savannah species such as *G. morsitans*, each fly may disperse up to 500 metres in a single day, so that with an average trap density of just four traps per km^2, there is a high likelihood that each fly may disperse sufficiently to encounter at least one trap (Hargrove, 1993; 2003[a],[b]). By contrast, forest species such as *G. fusca* probably disperse little more than 5-10 metres per day, so that effective trap densities need to be very much higher (see section 3.2.3).

As trypanosomiasis control tools, the same principles apply, in the sense that a reduction in tsetse density should lead to a reduction in trypanosomiasis transmission. Overall, the relationship is non-linear, extending from the point of <zero flies: zero transmission> to a theoretical plateau at which all susceptible hosts would be infected irrespective of increasing fly density. Nevertheless, it is generally held that over the practical range of host infection rates, the relationship between tsetse density and trypanosomiasis transmission is sufficiently close to linear to warrant that reduction in fly density will lead to reduction in the likelihood of transmission. This was originally suggested by Rogers (1979[b]); subsequent analysis of past field data indicated an effectively linear relationship between percentage reduction in man-fly contact and percentage reduction in human sleeping sickness incidence in West Africa (Rogers, 1985). This conclusion also held for data from studies of cattle infection in East Africa, involving *G. morsitans, G. swynnertoni, G. pallidipes, G. fuscipes, G. longipennis*, and *G. brevipalpis*, where the daily probability of infection was linearly correlated with tsetse challenge (apparent fly density x infection rate) (Rogers, 1985).

In general therefore, it can be argued that deployment of traps and/or targets that destroy a proportion of the tsetse population will lead to a reduction in trypanosomiasis transmission. Moreover, in the case of human-infective trypanosomes, where the infection rate in the flies tends to be very low, the infection will be unable to spread once the vector population is below a threshhold level (Rogers, 1988; Atzrouni & Gouteux, 1996, 2001), so that an outbreak of human infection could be contained by a sustained trapping campaign that keeps the density of tsetse vectors below that threshold (Gouteux & Artzrouni, 1996).

3.2. HISTORICAL ASPECTS OF TRAP DEVELOPMENT

3.2.1 Summary

Sticky back screens employed on the Island of Principe against *G. palpalis* provided the first indication that tsetse flies could be controlled by artificial devices. These were first deployed in 1910; they consisted of a black cloth coated with lime, carried on the back of a plantation worker. By this means, *G. palpalis* was successfully eradicated from the Island in 1914 (Da Costa et al., 1916). There was reinvasion by *G. palpalis* in 1956 – presumably carried across the sea from the African mainland – but this was quickly eradicated by insecticide spraying (De Raadt, 1999).

Since this early demonstration of the efficiency of trapping devices, a wide range of designs has been developed. The first of these was the Harris trap, which originated from field observations on the response of tsetse flies to visual stimuli. This trap, similar to a malaise trap, was based on the principle that tsetse were attracted by a dark vertical screen, then moved upwards into the body of the trap, and then into a holding cage (Harris, 1930). After 1931, over 11 000 Harris traps were deployed against *G. pallidipes* in and around the Umfolosi game reserve in Zululand, South Africa (an area of approximately 280 km^2). Catches declined dramatically, and by 1938 it was thought that the fly had been effectively eradicated (Harris, 1938). Re-analysis of Harris' original data (Hargrove, 2003[a]) indicates that the original *G. pallidipes* population density was about 39 000 flies per km^2, and that the traps had imposed a daily mortality rate of 5-9%, well above the theoretical level required to eliminate such a population (see Hargrove, 1988). Nevertheless, Harris' results show that this tsetse population was not in fact eliminated; as pointed out by Hargrove (2003[a]) *"The problem lies in the fact that the area treated was too small and that a residual tsetse population surrounding the reserve formed a source of reinfestation."*

Following from Harris' experience, Swynnerton (1933, 1936) developed a variety of similar traps which were intensively tested in Tanzania, but neither these models nor models of the Harris type were as successful as the Harris trap in Zululand. Chorley (1933) also described 'crinoline' and 'ventilator' forms of trap, which he used against against *G. palpalis* (*G. fuscipes*) in Uganda. As a development of the Harris' idea, Morris & Morris (1949) introduced the 'animal' trap, which was designed to look like an animal in shape. They used these traps against *G. palpalis* and *G. tachinoides* in West Africa, but initially concluded that the traps could not compare in efficiency with selective clearing of vegetation, which was then widely practiced as a method of tsetse control. Later, Morris (1960, 1961) came to regard traps as a more efficient means for sampling tsetse populations and studying their distribution, compared to the then conventional fly round involving field workers catching individual flies in handnets. Morris also observed marked reductions in fly incidence in areas where traps were in operation, and advocated their use, combined with human settlement, for reclaiming land from *G. pallidipes*. Based on studies on *G. palpalis* in Liberia, Morris further claimed that traps could reduce fly populations to a level at which sleeping sickness was not transmitted. However, experience with other *Glossina* species in East Africa led to the general conclusion that traps were too uncertain in operation to provide a reliable means of control, and that the difficulties of siting them to give consistent and comparable catches were too great to provide an effective method of investigating the number of tsetse flies present. WH Potts wrote (in Mulligan, 1970) *"It would therefore appear that, generally speaking, the use of traps is an unsatisfactory method of controlling tsetse flies and that opinion is divided on their value as a means of investigation"*. Interest in trapping waned.

Until the middle of the 20th century, tsetse control continued to be based mainly upon bush clearing and selective game destruction, combined with ground spraying of dry season resting sites and aerial spraying of the known tsetse habitat. Moloo (1973) and Langridge (1975) then developed new traps as modifications of Swynnerton's design (1933, 1936), based on the same principle as the Harris trap. In East Africa, Vale (1974) developed a quantitative approach to trap development with the

incorporation of electric grids for the assessment of various parameters of trap efficiency, especially to determine what percentage of tsetse visiting a trapping device are actually caught by it. Vale showed that the electric grids knocked down approximately 95% of tsetse colliding with them, so that the efficiency of different trap designs could be determined by comparing their performance with that of an electric grid under the same conditions. This approach provided a rationale for understanding specific design features and linking trap design to the behaviour of the tsetse fly. The compound eyes of *Glossina* can perceive shape, colour and movement; moving objects are perceived at a much greater distance. *Glossina* species also seem capable of colour discrimination; phthalogen blue is particularly attractive, whereas black and UV-reflecting white tend to stimulate landing, and yellow tends to be unattractive (Green, 1986; Green & Flint, 1986). To summarize a detailed series of experiments by several groups, it was found that a combination of blue and black cloth was efficient, especially when arranged in a form such that some movement of the cloth was possible. The widely used pyramidal and monoconical traps exploit this idea, with an arrangement of blue and black cloth under a white netting to funnel flies into a holding cage. The biconical trap, developed for use against palpalis and fusca groups in West Africa (Challier & Laveissière, 1973), also exploited the idea of contrast between the body of the trap and the background vegetation. The attractiveness of this trap to the flies is entirely visual, and it is designed with a dark cavity into which the flies enter. The biconical trap, with its later improvements (e.g. Challier et al., 1977; Gouteux, Challier & Laveissière, 1981), has since been widely used against *Glossina* species in several countries, particularly in West and Central Africa.

Over the following years, many different designs of tsetse trap and target were developed, which played a significant role in the control of tsetse and human African trypanosomiasis (see Annex 1). Prominent among them were the monoconical trap (Lancien, 1981), the pyramidal trap in the Congo (Gouteux & Lancien, 1986), the Vavoua trap in Côte d'Ivoire, which was reported to be as efficient as the biconical and pyramidal traps but half their cost (US$ 3.5) (Laveissière & Grebaut, 1990), and the mono-screen trap for *G. f. fuscipes* in Uganda (Okoth, 1991). More complex 'cubical' traps were also developed for specific situations, including the recently developed H-trap for *G. brevipalpis* in Kwazulu Natal (Kappmeier, 2000).

Simpler and cheaper targets were also developed as screens of cloth impregnated with insecticide, so that tsetse attracted and landing on them would be killed by contact with the insecticide deposits. One type of target developed by Vale, Bursell & Hargrove (1985) and Vale et al. (1986) for *G. pallidipes* and *G. m. morsitans* in Zimbabwe was the S type, which consists of a black rectangular sheet of cloth flanked by two sheets of black mosquito netting, fastened to a metal frame swivelling on a single pole sunk into the ground. As screens do not retain tsetse, they must be impregnated with insecticide. In West Africa, Laveissière, Couret & Grébaut (1987) designed a similar screen (target) for use against *G. palpalis*; the final design consisted of a blue central cloth flanked by two strips of black mosquito netting. To discourage theft, slits were made in the blue cloth. Similar designs, typically involving blue/black/blue sheets on a simple metal or stick frame, with the cloth slit to avoid theft, are now also widely used throughout East Africa. The screens carry a sachet of odour bait (see 3.2.2) and are treated with a biodegradable pyrethroid such as deltamethrin, either by impregnation or spraying. Some formulations are also applied with a UV absorber to reduce UV degradation of the insecticide, and/or with dilute black dyes to reduce the colour fade.

3.2.2 Odour-baited traps and targets

In addition to the developments in shape and colour of tsetse traps, a significant advance came with the development of odour baits that could dramatically increase the attractiveness of these devices. Earlier workers (Swynnerton, 1933; Lloyd 1935) had observed that a trap incorporating an animal hidden from view caught more flies than a similar trap without an animal, suggesting that host

odours could increase trap efficiency. This was clearly demonstrated by Vale (1974) and colleagues in a major series of studies showing that odours derived from different animals could alter the attractiveness of stationary traps. Odours derived from oxen, donkeys, goats, sheep, buffalo, bushbuck, and bushpig, were attractive, whereas odours from people were repellent. Subsequently acetone and octenol (1-octen-3-ol) were found to be potent olfactory attractants for *G. m. morsitans* and *G. pallidipes*, and could be successfully used as trap baits (Vale et al., 1986). A further breakthrough came from the work of Owaga et al. (1984, 1985) in Kenya, who showed that buffalo urine increased *G. pallidipes* trap catches up to ten times. The attractive component of urine was found to lie in the phenolic fraction (Hassanali et al., 1986; Bursell et al., 1988; Owaga, Hassanali & McDowell, 1988).

Extensive subsequent research involving chemical synthesis, electroantennagram recordings from tsetse exposed to candidate compounds, and experimental studies in wind tunnels and in field situations, has led to the development of a series of attractants and attractant mixtures suitable for trap and target baiting against various species of tsetse (see Table 2). These can be dispensed from simple polythene sachets inserted in a cloth pocket sewn onto the trap or target (Laveissière, Vale & Gouteux 1991).

TABLE 2. PRACTICALLY USEFUL OR PROMISING ODOURS AS ATTRACTANTS FOR TSETSE (from: IAEA, 2003)

G. brevipalpis	POCA* + decanal POCA + *P. sylvestris* oil POCA + isovaleric acid
G. palpalis gambiensis	POCA octenol + cow urine octenol + cow urine + acetone octenol + dodecanal + acetone
G. tachinoides	POCA POCA + *P. sylvestris* oil POCA + *P. sylvestris* oil + decyl formate m-cresol + octenol m-cresol + octenol + acetone octenol + cow urine octenol + cow urine + acetone *P. sylvestris* oil
G. fuscipes fuscipes	*P. pumilionis* oil
G. morsitans submorsitans	m-cresol + octenol octenol + cow urine octenol + cow urine + acetone
G. morsitans centralis	POCA POCA + octyl formate POCA + decanal *P. sylvestris* oil
G. austeni	octenol + acetone POCA
G. pallidipes	acetone octenol + acetone POCA POCA + decanal POCA + octyl formate POCA + *P. sylvestris* oil POCA + *P. pumilionis* oil
G. swynnertoni	acetone POCA POCA + decanal POCA + octyl formate

* POCA is an odour blend of propylphenol, octenol, p-cresol and acetone

3.2.3 Trap deployment

Efficient trap deployment represents a compromise between high trap density to maximize the likelihood of fly capture, and low trap density to minimize the costs. Dransfield (1984) carried out a series of experiments in which several unbaited biconical traps were arranged in a row in open grassland and the catches monitored as the traps were brought progressively closer together. When the ranges of attraction overlapped, the catch in the centre trap fell. The results of these experiments gave ranges of attraction of 15 to 20 m for *G. pallidipes* and 10 to 15 m for *G. brevipalpis*, which is possibly the limit of attraction for unbaited stationary traps.

By contrast, field experiments indicate that morsitans group tsetse respond to odours from a cow at distances of up to 50-100 m downwind of the odour source (Bax, 1937; Vale, 1974). Once flies enter an odour plume, they tend to fly upwind (Vale, 1974; Gibson & Brady, 1988); in wind tunnel experiments, flies take off upwind in the presence of suitable odours (Torr, 1988). The role of wind is not entirely clear in determining attraction to odour-baited traps and targets, since wind speed is often very low in many tsetse habitats (Brady, Gibson & Packer, 1989), and the wind flow below the canopy of a woodland is usually turbulent and unpredictable (Elkinton et al., 1987). Nevertheless, as argued by Williams, Dransfield & Brightwell (1992), 100 m seems the probable limit of attractiveness for most odour-baited traps and targets.

These features, combined with the expected displacement rate of target flies, are important for efficient trap deployment. At a trap density of 4 per km^2, as recommended for elimination of *G. m. morsitans* and *G. pallidipes* (Vale et al., 1988; Hargrove 1993, 2003[b]), the maximum displacement required of any fly in order to enter the range of trap attractiveness would be 253 m (Fig. 3), which is well within the daily root-mean-square displacement of 167-1300 m calculated on the assumption of displacement by random diffusion (Williams, Dransfield & Brightwell, 1992).

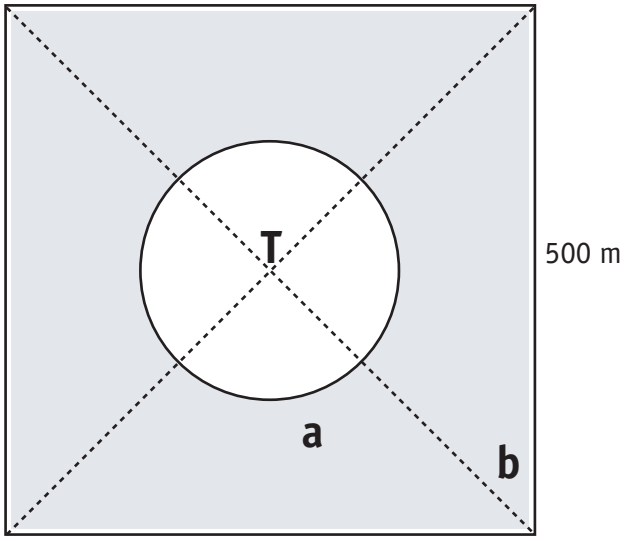

Fig. 3 In a 1 km square, with four evenly-spaced odour-baited traps, then each trap (T) is within a 500 m square. If each trap has a radius of attraction of 100 m (distance Ta), then the maximum displacement to reach that area will be distance b a (253 m) [sqr(2 x 500^2)/2] - 100

The situation for forest and riverine conditions is less well understood. Multiple mark-release studies in riverine forest along the Koba and Woyowonko rivers in Mali using biconical traps to monitor recapture of *G. p. gambiense*, indicate average maximum dispersal rates of 87-219 m per day, up to a maximum displaced distance of 7.5 km over a period of 57 days (UCLT, 2004). However, similar studies in Burkina Faso indicated linear fly dispersal to be 600-2000 m per day up to a maximum of

about 20 km (Cuisance et al., 1985). Given these linear dispersal rates, trap deployment of around 10 per linear km would seem adequate in riverine habitats, although good results have also been reported against *G. palpalis* with only one trap per 300 m (Laveissière & Grébaut, 1990). In gallery forest however, species of the palpalis and fusca groups tend to disperse much less, requiring a considerably higher density of traps and targets – up to 250 per km^2 if only small areas are controlled, although trap density can be reduced over larger areas (Laveissière, Couret & Grébaut, 1986). Summarizing the Vavoua trials against *G. palpalis*, Laveissière & Grébaut (1990) explain: *"1000 screens in 4 km^2 had a definite effect, but 16,000 screens...over 86 km^2 had a better effect, and 36,000 screens in 1300 km^2 were even better"*.

3.2.4 Traps and targets as barriers to reinvasion

Aside from questions of political commitment and availability of resources, the main technical difficulty with tsetse control is the large and heterogeneous areas that must be considered. Small-scale interventions rapidly become unsustainable as control efforts are relaxed and flies reinvade from surrounding areas (see section 4). But even large-scale interventions face similar problems unless the entire target population can be eliminated. This requires adequate definition of the biogeographical limits of the target population (for example through detailed population genetics studies) and/or intervention over a geographically limited area – as in the case of tsetse elimination from Unguja Island, Zanzibar (section 6.2).

Another approach is to set up a barrier between the treated area and untreated regions from where flies might reinvade. In some cases natural barriers are available, including habitats which are inhospitable to tsetse e.g. the 35 km channel (in the Indian ocean) between the island of Zanzibar and the mainland (and similarly for Principe Island in the Atlantic Ocean), or mountain ranges above 1800 m, which seems to be the altitudinal limit of most tsetse species. Alternatively, artificial barriers can be developed using available control techniques such as traps and targets (Table 2). For riverine species such as *G. palpalis*, Laveissiére & Grébaut (1990) recommend that such barriers should be at least 5 km wide, with at least 10 traps/targets per km. In north-eastern Zimbabwe (Mudzi district), odour-baited targets have been employed as a barrier to tsetse invasion from neighbouring Mozambique (Muzari, 1999; Muzari & Hargrove, 1996), together with insecticide-treated cattle in some regions of the frontier (Warnes et al., 1999). The results, carefully analysed by simulation modelling and field experimentation, showed that barrier width – rather than trap density – was the key feature. *G. pallidipes* would have a probability of around 0.1 of penetrating a one kilometre wide barrier – even at a trap/target density of 64 targets per km^2; increasing the barrier width to 8 km would reduce this probability to 0.001 even at only 4 targets per km^2. Similarly, modelling the Rifa triangle experiment in Zimbabwe showed that odour-baited targets could not prevent the invasion of flies up to 5 km from the edge of the treated area (Hargrove, 2003[a],[b]).

A similar problem was faced in Botswana, where the objective was to eliminate *G. m. centralis* from the Okavango delta and prevent it returning from neighbouring countries. Control was achieved by sequential aerial spraying during 1973-1991. It was believed that the tsetse had been eradicated, but surveys showed that *G. m. centralis* was still present, although it is not known if these were survivors or immigrants (Wooff, 1992). During the 1990s, these tsetse populations increased, threatening tourism as well as cattle ranching in the region, so that a new aerial spraying campaign was started in 2001, designed to be followed by sterile male release (SIT) in case any of the original tsetse population survived, with extensive trap and target barriers along the frontiers to prevent reinvasion (TK Phillemon-Motsu, unpublished). By August 2002 however, it appeared that the aerial spraying had been entirely successful, so that SIT was considered unnecessary (TIC, 2002). Moreover, through AU-PATTEC (see section 6.4), the Government of Botswana made agreements with the governments of Namibia, Angola and Zambia to collaborate on extending tsetse control to cover the entire belt of *G. m. centralis* in this area, so that maintenance of frontier trap barriers may also become unnecessary (PATTEC, 2003).

3.2.5 Involvement of TDR and other international organizations in tsetse trap development

Starting in 1977, WHO/TDR in collaboration with other international organizations including FAO, Organisation de Coordination de la Coopération pour la Lutte contre les Grandes Endémies (OCCGE), Institut Français de Recherche Scientifique pour le Développement en Coopération (ORSTOM), and with national institutions in sleeping sickness endemic countries, sponsored research on the development and evaluation of traps and screens as simple cost-effective methods of tsetse control. These methods were considered best suited for sleeping sickness control and were acceptable to the rural communities. TDR's investment from 1977-1994 totalled over US$ 600 000.

Under the auspices of TDR, a meeting on *Glossina* trapping was held in Brazzaville, Congo, in March 1982, which brought together scientists from West, Central and southern Africa who were interested in *Glossina* trapping as a method of tsetse control. It was a landmark meeting, where trapping was accepted as a new approach to vector control based on decentralization of control operations and on community participation for their own protection. This meeting opened the way for better interaction between the scientists, and gave the impetus to improve trapping technology for tsetse control. From limited progress made in the Congo, it appeared that the association of trapping with medical surveillance rapidly interrupted sleeping sickness transmission (Lancien, 1981). The meeting, among other things, defined criteria for the selection of pilot control zones where similar activities could be implemented under different epidemiological conditions (TDR, 1982).

3.3 PRACTICAL EXPERIENCE WITH TRAPS AND TARGETS IN DIFFERENT CONTEXTS

3.3.1 Riverine habitats

In the moist Guinea savannah region, distribution of the *G. palpalis* group of flies is essentially riverine, with daily average dispersal rates typically above 100 m (Cuisance et al., 1985) but often less (UCLT, 2004) (3.2.3). For this reason, traps and/or screens are generally placed no more than 100 m apart. Screens impregnated with deltamethrin (100 mg a.i. per screen) have been used experimentally to reduce populations of *G. p. gambiensis* and *G. tachinoides* in riverine forest along the River Leraba, along the border between Burkina Faso and Côte d'Ivoire. Tsetse populations were reduced by 96% at an estimated cost of US$ 97 per linear km (Laveissière et al., 1981). In Mali, recent trials against the same species along the Koba and Woyowonko rivers achieved 98% reduction in apparent densities in as little as one month (UCLT, 2004).

In central Nigeria, near Lafia, the integrated use of biconical traps and impregnated targets followed by sterile male release (SIT) has been applied to eradicate *G. p. palpalis* from a 1500 km^2 area for agricultural development (Oladunmade et al., 1985; Takken et al., 1986). *G. p. palpalis* has been eliminated in certain areas. Similarly, a larger study over 2400 km^2 of the Koba and Sinlo basins in the pastoral zone of Sidéradougou, Burkina Faso, deployed insecticide impregnated screens and traps followed by SIT to eradicate *G. p. palpalis, G. tachinoides* and *G. m. submorsitans* (Politzar & Cuisance, 1984; Cuisance et al., 1990). This trial was highly successful, but subsequent lack of monitoring and progressive reinvasion of flies from neighbouring areas led to reconstitution of the tsetse populations (Malavasi, Sheesley & Schofield, 2004).

3.3.2 Forest zones

During the second half of the last century, the forest zones of West Africa were increasingly exploited for timber, subsistence farming, and cultivation of cash crops, particularly cocoa and coffee. These activities brought increasing exposure to forest species of tsetse, with increasing incidence of gambiense sleeping sickness. In terms of tsetse control, gallery forest represents a particular problem because conventional approaches using insecticide sprays become inefficient as the vegetation impedes the

dispersal of insecticide droplets. In the forest zones of Côte d'Ivoire for example, trials of tsetse control by aerial spraying of insecticides from a helicopter (Kuzoe et al. 1979) or by ground spraying (Sékétéli et al, 1985) were found to be unsatisfactory and inappropriate.

To develop a simpler and cost-effective approach to control tsetse in these regions of Côte d'Ivoire, Laveissière and co-workers deployed traps and targets. Because of the relatively low rates of dispersal of forest tsetse species, traps and targets had to be deployed in large numbers – up to 250 per km^2 (section 3.2.3). In a pilot study in the Vavoua focus, Laveissière et al. (1985) evaluated the use of impregnated screens for the control of *G. palpalis*, relying on community participation for deployment and maintenance of these targets. However, the overall reduction in tsetse population abundance did not exceed 90%, possibly due to the limited scale of the trial. In a larger study, over 15 000 impregnated screens were used in 451 coffee and cocoa plantations in an area of 8592 hectares. Deltamethrin was also sprayed from the ground along 108 km of routes and around villages, and impregnated biconical traps were deployed in the forest galleries. The response of the rural communities was good, and the trial achieved a reduction in tsetse populations of between 96.0 and 99.7% over a period of 8 months (Laveissière, Couret & Eouzan, 1986).

In forest zones of the Congo, monoconical traps impregnated with deltamethrin were used in the Niari and Couloir foci of sleeping sickness to reduce apparent population abundance of *G. palpalis* and *G. fuscipes quazensis* by 100% over a period of six months. Trap density of one per ten inhabitants around villages was adequate to achieve this level of control (Lancien et al., 1981). Impregnated screens were less attractive and considered to be ineffective against *G. f. quazensis* (Eouzan et al., 1981).

3.3.3 Savannah areas

Extensive studies of traps and targets against *G. morsitans* and *G. pallidipes* have been re-analysed in detail by Hargrove (2003[a]). These include the Antelope Island experiment (Vale et al., 1986), studies in Umfurudzi and in the Rifa triangle of Zimbabwe which deployed around 3000 odour-baited traps treated with deltamethrin in an area of 600 km^2 (Vale et al., 1988), the Nguruman experiment in Kenya which covered an area of nearly 200 km^2 (Brightwell et al., 1997), and the Sioma campaign in western Zambia which initially covered some 500 km^2 (Knols et al., 1993) but has since been extended to around 11 500 km^2 (Thakersi, 1997). In all cases, the results showed steep declines in tsetse population density – more marked for *G. pallidipes* than for *G. m. morsitans* in the case of the Zimbabwe experiments (Hargrove 2003[a],[b]) – with apparent local elimination being achieved in all except Nguruman, which was subject to annual reinvasion from untreated areas (Fig. 4). Simulation studies based on the Zimbabwe studies indicate that, for savannah species, a trap/target density of 4 per km^2 is quite adequate to achieve this level of control or local elimination (Hargrove 2003[b], Hargrove & Williams, 1998; Williams, Dransfield & Brightwell, 1992).

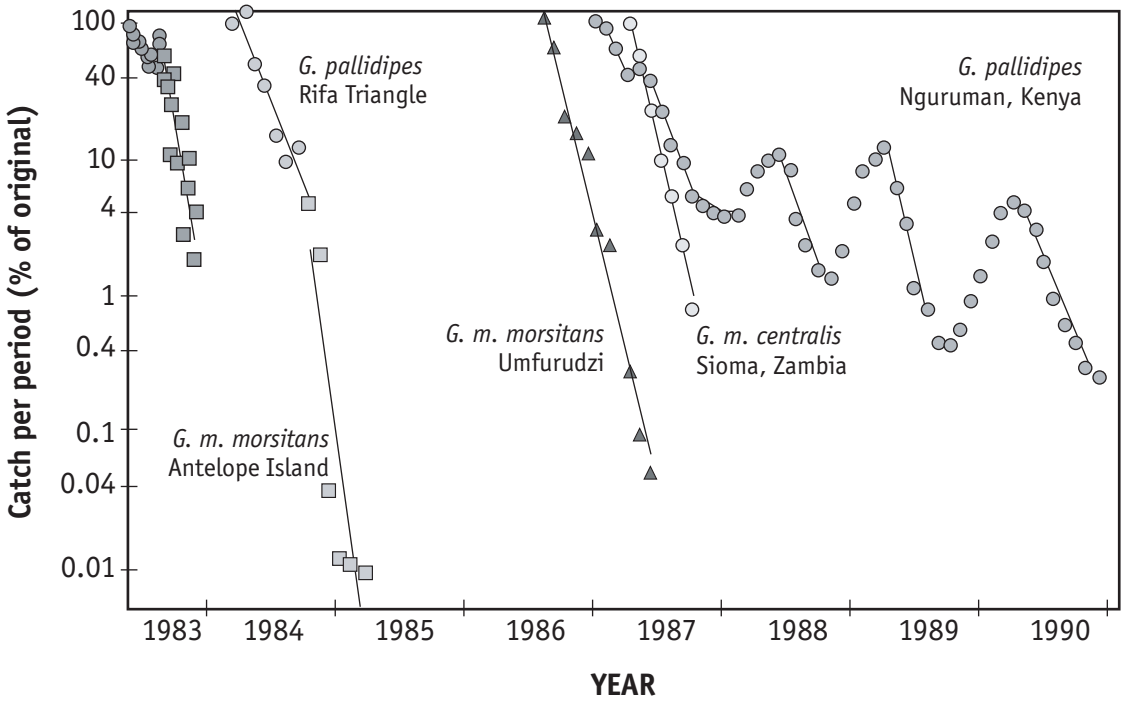

Fig. 4 Time course of operations using odour-baited targets and traps to eliminate tsetse in parts of Zimbabwe, Zambia and Kenya (reproduced from Hargrove 2003[a], by kind permission of the author and DFID-AHP)*

As Hargrove (2003[a],[b]) points out, these studies exemplify the capacity of trapping programmes to eliminate savannah species of tsetse from specified areas, but, except perhaps for the Antelope Island experiment, all such areas remain potentially susceptible to reinvasion from other regions. Sustainable success thus depends either on the size and biological isolation of the controlled area, or on the capacity to continue effective trapping along barriers to prevent reinvasion from non-controlled areas.

* Due to an error in the original, the Nguruman data have here been replotted, courtesy of Dr R. Dransfield

4. COMMUNITY PARTICIPATION IN TSETSE TRAPPING

4.1 BACKGROUND AND COUNTRY TRIALS

International legitimization for community participation in health programmes came from the Alma Ata Primary Health Care Conference in 1978. Clause IV of the Alma-Ata declaration stated that "People have a right and duty to participate individually and collectively in the planning and implementation of health care" (WHO, 1978). Some people prefer the term community involvement, others community based, but the idea implies active rather than passive engagement of the community in health activities. The concept of community participation in the control of African trypanosomiasis evolved out of the need for an integrated approach in which some of the responsibility for sleeping sickness control could be devolved to the primary care level. However, control of human African trypanosomiasis depends largely on regular medical surveillance (diagnosis and treatment) of populations at risk of infection and, although techniques for case detection have been simplified considerably, surveillance unavoidably requires certain skills and facilities that can be organized only at second level referral health centres or above.

In 1983, the 36th World Health Assembly issued Resolution WHA 36.31 on African trypanosomiasis. Among other things, this recommended "to study ways and means of making available and distributing to the Member States concerned diagnostic kits for simple and rapid case-finding in the field, drugs for treatment, and manuals to disseminate new and effective low-cost control techniques" (WHO, 1983). In addition to the need for medical surveillance, there was a perceived need for permanent measures of prevention which could be applied by the rural communities themselves. Community self-reliance was assumed to promote continuity of control efforts. Moreover, it was thought that the use of preventive measures by village populations themselves would reduce expenditure on trypanosomiasis control from national health budgets, which in most of the affected countries translated to less that US$ 10 per capita per year (De Raadt, 1989). Since the eradication of tsetse populations was not considered realistic at that time, the objective of tsetse control campaigns in epidemic situations was to reduce the vector population to a level at which disease transmission was significantly reduced or interrupted (WHO, 1998). Impregnated traps and screens provided simple and cost-effective tools to achieve this goal.

4.1.1 Community participation trial in Côte d'Ivoire

On the initiative of WHO, a project entitled "La Participation des Communautés rurales dans la lutte contre la Maladie du sommeil" was elaborated in 1986; it was carried out in Côte d'Ivoire in 1986-1990 in collaboration with the Government of Côte d'Ivoire, the French Government, and OCCGE. The objectives were:

1. to introduce community participation in sleeping sickness control in an area socially and economically representative of most of the endemic foci of *T. b. gambiense* transmission
2. to introduce simple means of vector control (traps and screens impregnated with insecticides) for application by local communities themselves
3. to introduce involvement of primary health care workers in case detection of new patients
4. to evaluate the effect of these combined measures on the density of local tsetse fly populations and on the transmission rate of the disease.

The results were published by Laveissière et al. (1994). Due to constraints in the choice of site, objective 3 was not pursued except in a further project at Sinfra, financed by WHO-TDR together with Fonds d'aide et de coopération français (FAC) and the Government of Côte d'Ivoire (Laveissière, Garcia & Sané, 2003).

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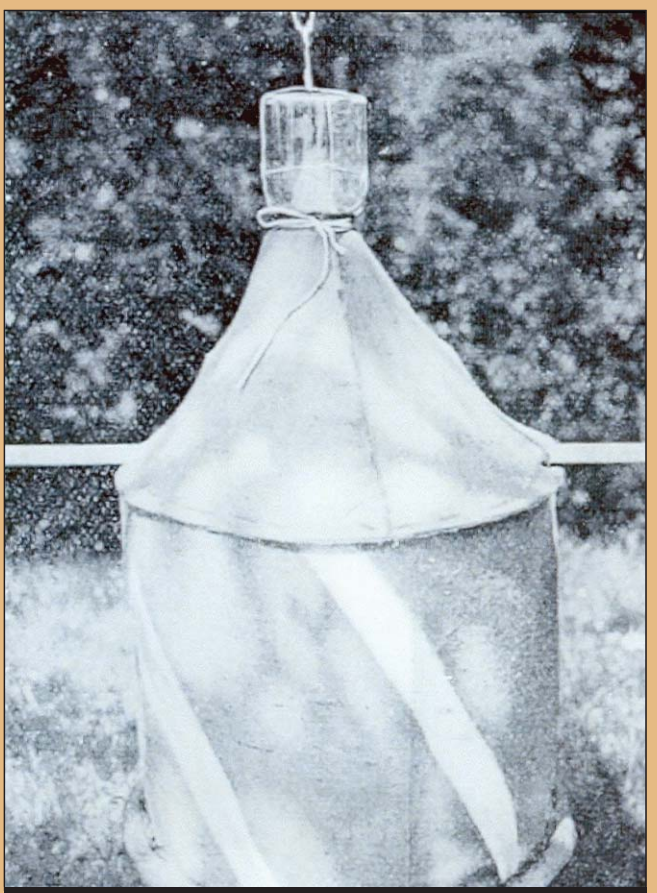
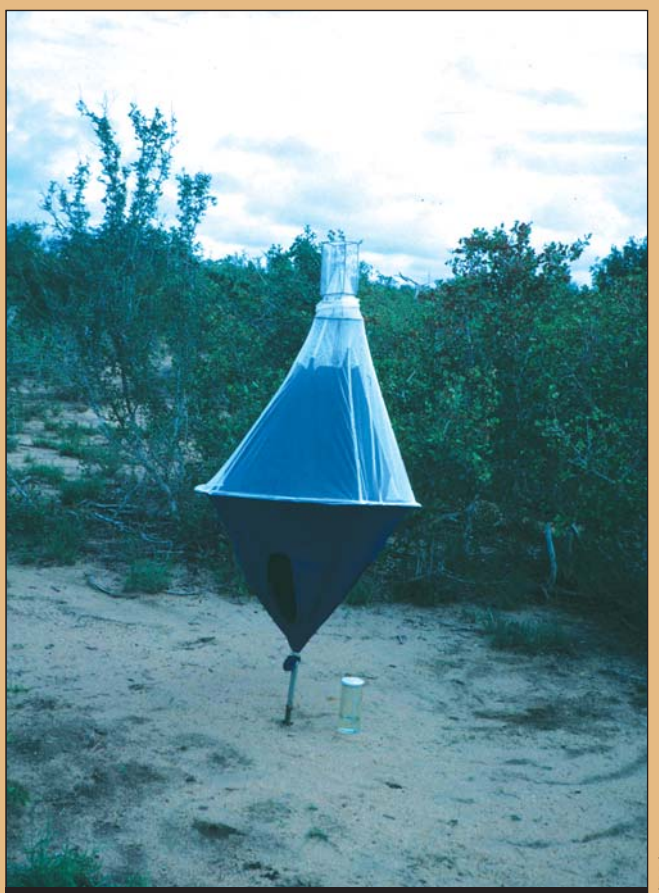


Chorley trap, 1933

CAB International

Langridge trap, 1975

WHO/TDR/Kuzoe



Biconical trap, 1973

WHO/TDR/Kuzoe

Monoconical trap, 1981

WHO/TDR/Kuzoe

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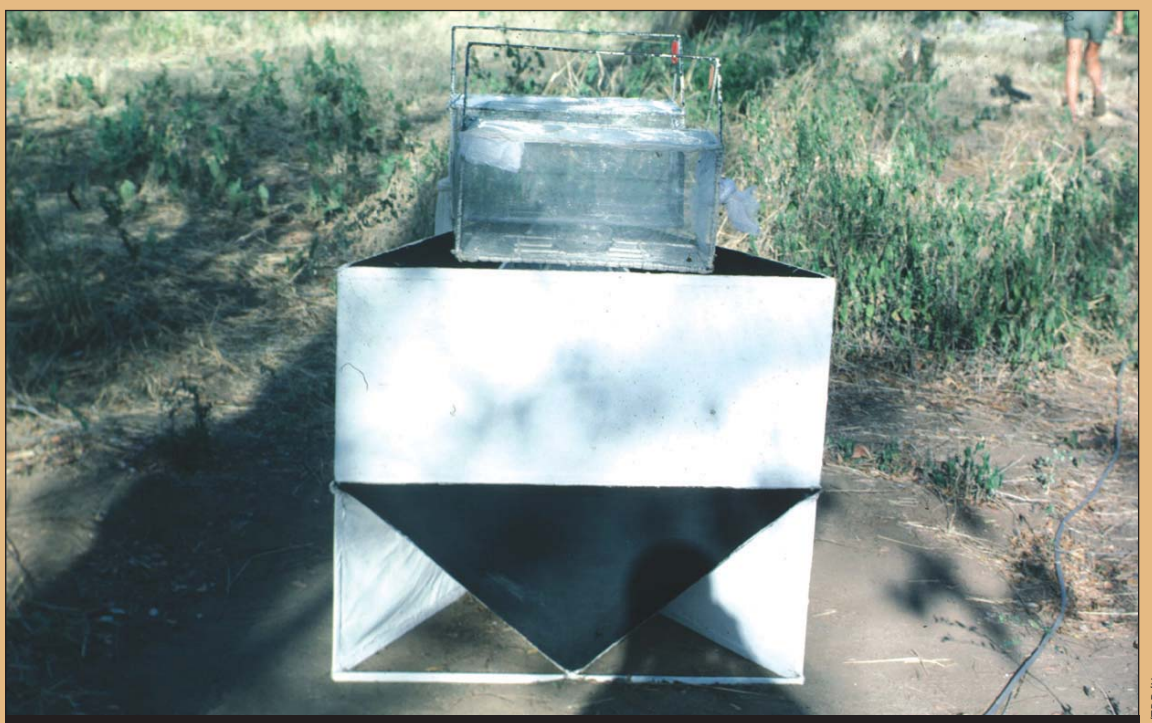

Beta trap, 1982

WHO/TDR/Kuzoe

Pyramidal trap, 1986

WHO/TDR/Kuzoe

NGU trap, 1987

WHO/TDR/Kuzoe

F3 trap, 1988

WHO/TDR/Kuzoe

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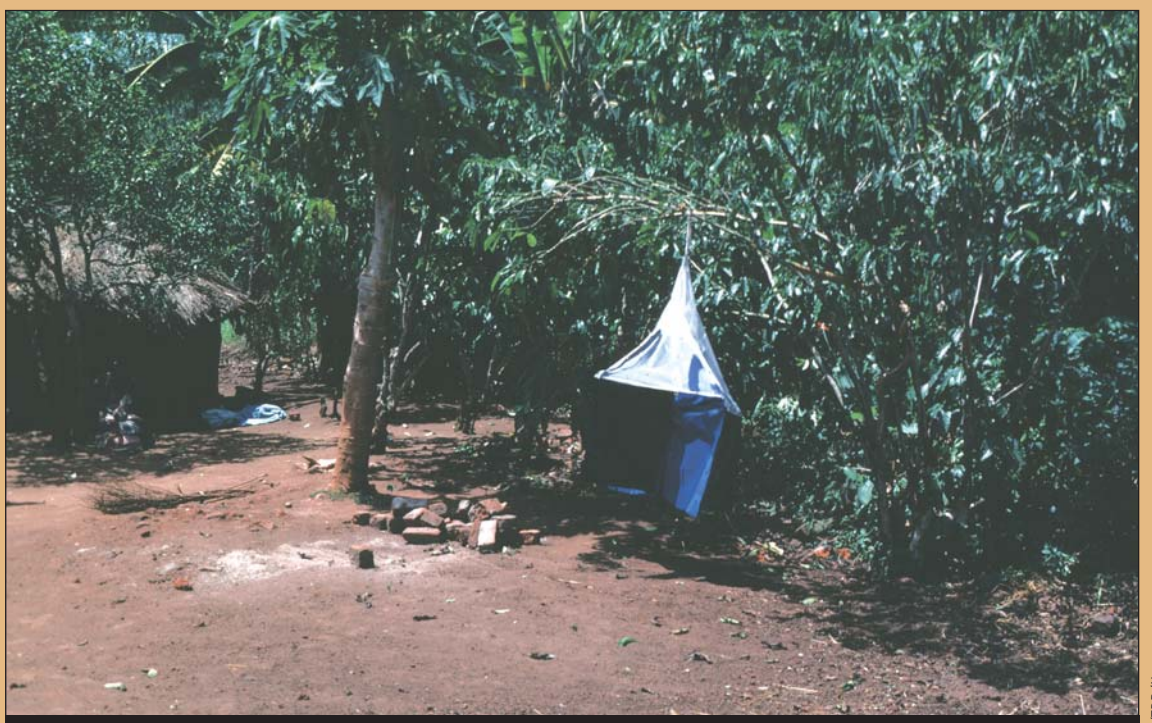

Vavoua trap, 1990

WHO/TDR/Kuzoe

Monoscreen trap, 1991

WHO/TDR/Kuzoe

Electric grid, Vale, 1974

WHO/TDR/Kuzoe

Screen-early model

WHO/TDR/Kuzoe

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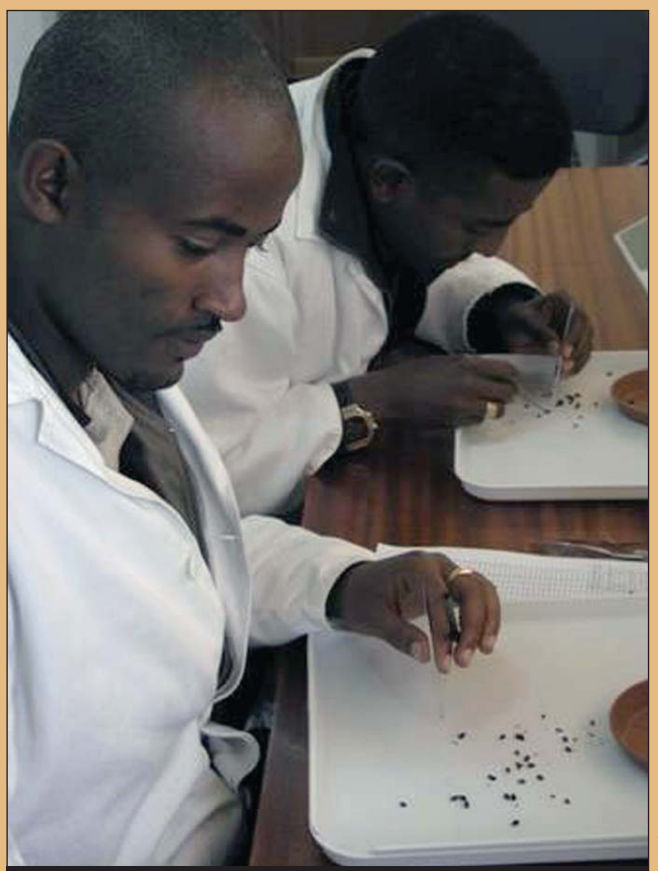
S trap, with chemical attractants

WHO/TDR/Kuzoe

Impregnated screen target

WHO/TDR/Kuzoe

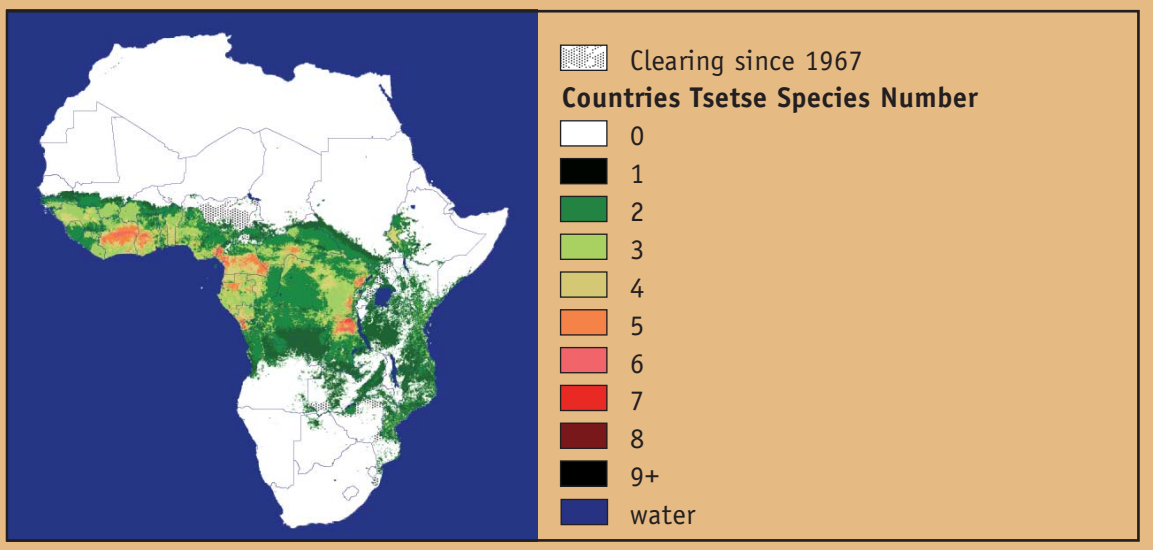


Technicians in Ethiopia's first tsetse fly breeding centre separate larvae before they hatch

Petr Pavlicek/IAEA

Tanga scoop

Prof. A.Malavasi



Produced in 2000 by the Environemental Research Group Oxford Ltd on behalf of the Department for international Development, London and the UN Food and Agriculture organisation, Rome

The campaign took place in the Vavoua focus, where a pilot study had previously been carried out (Laveissière et al., 1985; Laveissière, Couret & Eouzan, 1986) (see 3.1.2). Vavoua is located in the transitional forest savannah zone, which has been cultivated intensively for cocoa and coffee plantations and subsistence farming. The area of study covered 1500 km^2; it included some 54 villages with multi-ethnic populations, most of whom were migrant farmers, from neighbouring Burkina Faso and Mali, living in temporary settlements within the area. The complex ecosystem of forests, plantations and bush tracks was ideal for high human fly contact and transmission of sleeping sickness.

Insecticide-impregnated screens (black/blue/black) were used at a cost of 957 francs de la Communauté Financière d'Afrique (CFA)[4], plus impregnation costs of 22 CFA /per screen per impregnation (deltamethrin at 90 mg a.i./screen). In all, 3436 farmers participated in the campaign. After basic training in tsetse and trypanosomiasis control activities, including insecticide-impregnation of screens, they distributed 41 000 screens at various strategic points in the control area. Vavoua traps were also deployed on the outskirts of villages and forest galleries, and were also impregnated with deltamethrin at 400-500 mg a.i./trap at a cost of 1189 CFA, excluding trap support or labour costs.

At the initial distribution of materials in March 1988, almost 87% of the farmers were present. In June-July of that year, participation decreased to 84% because some farmers were preoccupied with their subsistence farms or had not returned from their villages of origin. In November, participation rose to 85%. In May 1989, participation decreased to a minimum of 77.5% because this was the period when the non-indigenous farmers returned to their home countries. This period also coincided with the time of crop harvest and clearing of plantations. In other words, community participation in this project was highly influenced by population movement and seasonal activities of the people. The screens were also subject to theft. Between July 1988 and November 1989, 2504 thefts of screens were reported, representing 6.5% of the number distributed at the start of the campaign.

The placement of traps around villages and of screens in plantations reduced the apparent density of *G. p. palpalis* from the low initial average of 0.01 flies per trap per day, to zero, although the impact of this on human trypanosomiasis transmission could not be assessed because all human cases in the Vavoua focus had been previously cleared by medical surveillance and treatment. No case had been reported from Vavoua since 1982, and no case was diagnosed in the zone between 1987 and 1990 by medical survey teams.

Costs of the campaign have been expressed in different ways, and translated to an average of 312 CFA per hectare per annum (approximately US$ 100 per km^2). If the campaign had continued, it was estimated that costs could have decreased progressively to 44 CFA p.a. Costs per farmer were 12 700 CFA; costs per inhabitant in a population of 25 789 were 1813 CFA; costs of medical surveys were 6 182 000 CFA or 238 CFA per person examined.

The follow-up project at Sinfra was implemented between 1995 and 1997. Trained community health workers (CHWs) carried out health education and censuses of the population, mapping the extent of the sleeping sickness focus through serological diagnosis of sleeping sickness patients, and of tsetse control by trapping. As in the Vavoua project, trapping was directed against *G. p. palpalis*, using Vavoua traps for the village periphery placed by the CHWs, and the black/blue/black screens, which were distributed to farmers. The strategy allowed coverage of an extensive region, and provided a reasonable level of health care to the population. The overall costs of tsetse trapping came to 16 441 420 CFA, which translates to 183 CFA per hectare protected or 2 800 CFA per farmer – considerably less than those of the Vavoua project.

[4] At the time of this project, US$ 1 = 350 CFA

4.1.2 Community participation trials in Uganda

An epidemic of rhodesiense sleeping sickness started in 1976 in the Busoga focus, southeast Uganda, along the northern shores of Lake Victoria. More than 40 000 cases were reported. By 1988, the epidemic had spread to the neighbouring district of Tororo. A tsetse control programme was initiated in 1988 in Busoga District, using pyramidal traps impregnated with deltamethrin. This programme was gradually extended to cover the entire Busoga focus by 1989, and to Tororo District in 1990 (Lancien, 1991).

The main vector was *G. fuscipes*, which was widely distributed, especially in degraded forests and plantations which were the main points of human/fly contact. Tsetse also occurred in peridomestic habitats, especially in *Lantana camara* vegetation around villages. The apparent tsetse density was 1 to 3 flies per trap/day, with a seasonal maximum in April and minimum in December.

The control operations were the responsibility of the Tsetse Control Department of Uganda; financing of the operations was provided by the European Commission (EC), French Government, WHO, and Government of Uganda; and the operations were directed by a WHO international staff member and a national counterpart. Each district was under the supervision of a field officer and a training officer. Below this level were field assistants, who were each in charge of two or three sub-counties, each sub-county being an administrative region of 150 km^2 comprising 16 000 inhabitants. In each sub-county, the responsible officer for trapping was locally recruited and trained in how to place and maintain the traps, and how to develop community awareness. Community involvement in the programme was directed by local committees for sleeping sickness control, who educated the villagers about the disease and tsetse control, and solicited their participation in placing, surveying and maintaining the traps. These local committees also worked in close collaboration with the locally recruited responsible officers, so that community participation in this programme was designed to supplement government and international efforts to control the epidemic.

Pyramidal traps used in this operation were manufactured by locally recruited people, and impregnated with deltamethrin at 300 mg a.i. per trap. They were deployed at an average density of 10 traps per km^2, and were impregnated only once, being replaced by new impregnated traps after eight months. Even though the period of efficacy of the insecticide is less than eight months, the traps remained effective because they still caught and retained flies, which eventually died from exposure (due to heat). The villagers knew the locations where tsetse were concentrated, and helped in placing the traps for maximum efficiency. The total number of traps deployed was progressively increased, from around 6000 in 1988, to 10 000 in 1989, to 12 000 in 1990. As the results progressively showed a reduction in tsetse populations, the number of traps was later halved, retaining only those that were placed in strategic locations (where flies were still being captured). Since cattle are also a reservoir for *T. b. rhodesiense*, surveillance and treatment of cattle with veterinary trypanocides was included as a component of the control interventions. Studies in Tororo District confirmed that up to 50% of the cattle were infected with *T. brucei*, and that 25% of these infections had zymodemes similar to those found in human infective trypanosomes (in: Lancien, 1991). In Tororo district also, trapping was supplemented on an experimental basis by monthly insecticide pour-on treatment of cattle with deltamethrin (Spoton® containing 1% a.i. delivered at 10 ml per animal).

Generally, the reduction in apparent tsetse population density was rapid – 75% within one month, 90% in two months, and 99% from the fourth month onwards. In Tororo district where trapping was supplemented with monthly cattle pour-ons, the tsetse population was more rapidly reduced – by 99% within one month. The impact of the combined interventions on transmission of the disease was indicated by the reduction of incidence of new cases. In 1987, there were 1680 cases of first-stage sleeping sickness in the Busoga area. From the time the traps were introduced, the number of cases decreased progressively, to 594 in 1988, 206 in 1989, and 62 in 1990. In several counties,

no further cases were reported in the following year. In addition, interruption of *T. brucei* transmission and a decrease in *T. vivax* transmission were noted in cattle, highlighting the possible use of sentinel animals to evaluate the effect of trapping. A reduction in antibody level in domestic animals would indicate reduction in transmission, as has also been observed in sentinel animals such as pigs and sheep in the Republic of Congo (Gouteux, Toudic & Sinda, 1988).

The annual budget of this programme in Busoga/Tororo was US$ 300 000. The cost of a pyramidal trap was US$ 3, and the overall intervention costs were estimated at US$ 140 per km^2 (including personnel and logistics costs of US$ 95 per km^2). Human population density was 100 per km^2, so that the cost of each individual protected was estimated to be equivalent to US$ 0.9 per person per annum (Lancien, 1991).

In a concurrent project in the Iganga District of Busoga, attempts were also made to transfer the trapping technology to the rural community (Okoth, 1991). The trap used was a mono-screen trap comprising locally available plant parts for the framework, a screen covered partly by blue and partly by black cloth, and the cone covered by mosquito netting. This community had experienced sleeping sickness epidemics for over a decade, and the willingness of the community to participate in tsetse control was high. Community leaders expressed willingness to provide traps for themselves at a cost of 1600 Uganda shillings (US$ 4.2), which they considered relatively small in relation to the cost of receiving treatment for sleeping sickness. The overall strategy of the trapping programme was discussed with political and administrative leaders, who decided on the construction and placement of the traps, at their own cost, at strategic locations, such as near homesteads, waterholes, and in rice fields, to reduce human/fly contact. The contribution per group in Uganda shillings varied between 90 and 300 for cattle farms, between 30 and 100 per user of wells, and was 180 per rice farmer. Over a 3 month period, the villagers made 66 traps and placed them at a density of 4-8 per km^2. The traps were numbered and each trap owner kept a fly record sheet. Appointed persons collected the records of fly catches in the area and submitted them to the researchers. The fact that almost every family had been directly or indirectly affected by sleeping sickness would have been a motivation for getting involved. There were 69 sleeping sickness patients during 1989 prior to the community tsetse control activities. During the control period (January to December 1991), no sleeping sickness patient was reported in the area. In addition, the incidence of *T. brucei* in cattle was reduced from 1% to 0.6%.

This project was described as a success: traps were deployed, trap catches decreased progressively to zero, and no case of sleeping sickness was reported in the study area for over a year. However, Okoth (1998) reported that it was the project representatives who were directly responsible for most of the control. He stated, further, that there was little general community participation, and that this lack of involvement made sustainability in this and other projects questionable. He suggested that a larger proportion of each local community needed to be informed about tsetse control and encouraged to participate in it, and decided to study the use of theatre to mobilize and sensitize rural communities. In this way, he was able to increase awareness, and local civic leaders donated funds (US$ 1100) from the council budget to pay for local traps, while villagers expressed interest in participating in tsetse control. There is always the probability however that motivation will wane when the fly population or nuisance decreases or becomes zero. Okoth (1991) pointed out that, in Uganda, the rural communities are peasant farmers, and their land tenure is by customary inheritance, so, since there is no large migration in these communities, the transfer of a technology such as tsetse trapping can be seen as a long-term investment. The people can place the traps at sites where they know tsetse bite and thereby reduce the population; however, once the incidence of the disease is reduced and the tsetse nuisance removed, it is likely that the community might lose interest and stop operating the traps.

4.1.3 Community participation trials in Angola

There was resurgence of sleeping sickness in Angola from the mid 1980s, transmitted mainly by *G. fuscipes* s.l. and *G. palpalis*. Control interventions in northern Angola were implemented by the nongovernmental organization (NGO) ANGOTRIP, which is part of Caritas de Angola. These interventions included vector control as part of a control strategy involving active case finding and treatment of patients. About 3000 pyramidal traps were used where tsetse habitats overlap with human habitation, waterholes, along river banks, farm areas and other places where the population indicated they were being bitten. Community participation involved weekly emptying of traps, and maintenance of traps, by volunteers from nearby villages. Neither entomological evaluation nor impact of the trapping on disease transmission were part of the study. However, the population near the treated sites said they were bitten less often after the start of the intervention. The traps helped to mobilize the communities and to convey messages on African trypanosomiasis control far beyond fighting the tsetse fly (Abel et al., 2004). No costs were provided.

4.1.4 Community participation trials in Sudan

South Sudan experienced a resurgence of sleeping sickness in the 1990s. In 1997, tsetse trapping was used in combination with mass screening and treatment of infected persons. Trapping involved community participation in the making, setting and maintaining of traps. Village volunteers and their neighbours were given health education on the causes and prevention of sleeping sickness, and were motivated to attend mass surveys and to seek treatment. Cluster surveys were conducted by the Cooperative for Assistance and Relief Everywhere (CARE), the International Medical Corps, and the US Centers for Diseases Control and Prevention, to determine prevalence of the disease.

In all, 3250 pyramidal traps made by local tailors and women's groups were placed at locations where people came in contact with the fly, such as village farm plots, water sources, and areas where people collect firewood. The traps were maintained by community volunteers. The estimated cost of maintaining a trap for a full year was 2000 Sudanese pounds (US$ 4). In the villages of Tambura County where screening, drug treatment and tsetse trapping were conducted, seroprevalence of sleeping sickness was reduced during 1997-2001 from almost 9% to less than 2%. The number of flies trapped dropped from 25 per trap per week at the beginning of the project to fewer than 3 flies per trap per week at the end. It was not possible to evaluate the direct impact of trapping on disease transmission, but it appeared that the tsetse trapping project had increased local interest and participation in the disease prevention and treatment efforts (Joya & Okoli, 2001).

4.2 EVALUATION OF COMMUNITY PARTICIPATION IN TSETSE TRAPPING ACTIVITIES

The examples from Côte d'Ivoire, Uganda, Angola and Sudan illustrate a variety of projects or trials of tsetse trapping involving community participation under different epidemiological situations of sleeping sickness. The level of community participation varied from one project to another, and there was no instance where the community was involved in the initial planning. Nevertheless, these and other trials illustrate that the local communities can participate effectively in tsetse control activities, contributing local knowledge as well as their efforts in making, deploying, and maintaining the traps. Clearly however, such involvement is only possible when the community is aware of the problem, and its members perceive benefit from their involvement with control activities. This seems most marked in areas experiencing sleeping sickness outbreaks, both because of the disease itself and also because of the costs of seeking and obtaining treatment. Similar criteria apply to tsetse control in areas of cattle trypanosomiasis, where several studies have indicated willingness of cattle farmers to participate and contribute financially to tsetse control activities, largely because of the cost to them of maintaining their cattle free of infection (e.g. Malavasi, Sheesley & Schofield, 2004).

Interviews with cattle farmers in southern Mali, for example, revealed great willingness to buy materials and deploy tsetse traps since these are seen to be much cheaper than regular dosing of cattle with trypanocides (S. Magou, unpublished).

In the Vavoua project however (4.1.1.), even though the financial contribution to tsetse trapping in the plantations amounted, to the farmers themselves, to only 4.8-5.6% of family revenue, the farmers were unwilling to pay. This may be due not to the farmers failing to see the importance of tsetse control, but probably to the fact that most were migrant workers and had other financial commitments. Moreover, apart from tsetse nuisance, there was little perceived problem since no sleeping sickness cases had been reported from that area for several years. In Uganda on the other hand (4.1.2), where the devastating impact of sleeping sickness was well known because of the epidemics, there was good response in the local population, but only for a while. As the fly nuisance and the number of patients decreased, interest waned. This is why it seems that trapping of tsetse may not be effective as a preventive measure. In a recent article (Ochan, 2004), Dr R. Mbulamberi, Assistant Commissioner of Vector Borne Diseases in the Ministry of Health, Uganda, was quoted as saying that lack of active community participation and involvement in control of sleeping sickness, and lack of targeted information about the importance and control of the disease, were amongst the problems responsible for re-emergence of sleeping sickness in Uganda. Dr. Mbulamberi also pointed out that national sleeping sickness control programmes had been sacrificed in favour of programmes for emerging public health problems such as HIV-AIDS.

There are clear difficulties in sustaining interest in continuous monitoring and control activities, both at national and community levels. This is apparent for the control of most diseases, especially where the interventions are successful in reducing the problem (see Vinhaes & Schofield, 2003). For the African trypanosomiases, Kuzoe (1993) pointed out that while ongoing control programmes tend not to appeal to international donors, it is a paradox that funds can be provided for epidemics, which are often disproportionately higher than those required for regular preventive measures. In epidemic situations such as in Uganda, Angola and Sudan (4.1.2 to 4.1.4.), donor support can be found to meet the costs of tsetse trapping programmes as well as medical surveillance. Once the epidemic has been brought down however, donor interest wanes.

The overall synthesis of experience therefore, is that community participation in tsetse surveillance and control should be sought, and is relevant wherever it can be developed. But this must be recognized as a potentially transient resource. Moreover, the activities cannot be entirely devolved to communities, who require consistent technical support, training, and encouragement to maintain their motivation. Tsetse trapping is a relatively simple technology which can be implemented by the community, and can have additional benefits of encouraging involvement and awareness of the disease and its vectors. Thus community participation in vector control activities can also improve attendance in medical surveys (Lancien, 1991; Joya & Okoli, 2001; Laveissière, Garcia & Sané, 2003). Epidemic outbreaks will clearly predispose communities to participate actively in the control programmes, but community-based interventions tend to be slow to start considering the time required to construct large numbers of traps and screens, develop awareness, and train volunteers. In an epidemic situation, like any emergency, a rapid deployment technique is necessary.

5. LARGE-SCALE INTERVENTIONS

5.1 BACKGROUND

Since the 1960s, tsetse control interventions have been mainly carried out at the level of national programmes or district and community projects. Most have relied on a limited suite of techniques, but all have achieved some level of reduction in tsetse density – to apparent extinction in some cases (see Hargrove, 2003[a],[b]). However, the initial reduction in fly density was often not sustained, either due to population recovery from a low number of survivors (e.g. Turner & Brightwell, 1986) or to reinvasion from uncontrolled areas (e.g. Brightwell et al., 1997; Vale et al., 1988), or to both (Hargrove, 2003[a]). It has become increasingly recognized that either some level of tsetse challenge should be accepted, or that the tsetse challenge should be eliminated entirely from specified areas in such a way that reinvasion is unlikely.

Even successful large-scale tsetse control operations have suffered from progressive lack of sustainability. In Nigeria for example, systematic ground spraying against tsetse cleared some 75 000 km^2 during 1970-75; supplemented with aerial spraying and trapping, this was progressively increased to around 250 000 km^2. Since 1991 however, as control activities were curtailed, tsetse have returned to many of the cleared areas (Allsop, 2001). Similarly, aerial spraying in Cameroon cleared some 25 000 km^2, but reinvasion of tsetse soon became apparent when the campaign was suspended (Cuisance & Boutrais, 1995). In Zimbabwe, large-scale tsetse control activities cleared some 148 000 km^2 during the 1960s, only to lose ground as interventions were disrupted during the war of independence. In the 1980s, operations were resumed with a combination of ground spraying, aerial spraying, odour-baited targets and insecticide-treated cattle, such that the incidence of cattle trypanosomiasis declined from 10 000 detected cases in 1984 to zero in 1997 (Hargrove, 2003[a]). But since tsetse have yet to be cleared from neighbouring countries, it is possible that cleared areas of Zimbabwe will become re-infested as control interventions are interrupted.

Problems have also been encountered with multinational programmes. In 1984, a four-country initiative for tsetse eradication was set up with European Union (EU) funding. This Regional Tsetse and Trypanosomiasis Control Programme for Southern Africa (RTTCP) initially involved Malawi, Mozambique, Zambia and Zimbabwe, and had the objective of using a range of techniques to eliminate tsetse from the entire 320 000 km^2 common tsetse belt (mainly *G. m. morsitans* and *G. pallidipes*) (Jordan, 1985). By 1988 however, the RTTCP had rejected the idea of using insecticides – due largely to misinformation about potential environmental impact (see Grant, 2001) – so that tsetse elimination was no longer feasible over such an area, and the programme was refocused on general rural development. The RTTCP was abandoned in 1995, but paved the way for a further EC funded initiative known as Farming in Tsetse Controlled Areas (FITCA)[5], which currently supports rural development activities in tsetse-infested regions of Ethiopia, Kenya, Tanzania and Uganda, including some community-based deployment of tsetse traps and targets.

5.2 EVALUATION

Throughout the extensive literature on tsetse and trypanosomiasis control projects and programmes, a common theme emerges concerning 'sustainability'. Invariably, the interventions achieve an initial reduction in tsetse density, regardless of whether a single technique is used, or a suite of approaches is employed concurrently or successively. At some point, the interventions are interrupted, and this is usually followed by recovery of the tsetse populations and recrudescence of trypanosomiasis transmission. From the examples given above, a range of factors can underlie the interruptions:

[5] http://ibar-fitca.org/

- Termination of a short-term project: most typically in the case of externally-funded research projects that reach the end of their planned course.

- Changing political priorities: can occur as a consequence of success of control interventions, when the initial problem has been reduced to a level that no longer appears so important.

- War and civil unrest: making it difficult, even dangerous, to continue activities in the field.

- External misconceptions: leading, for example, to withdrawal of donor interest due to misunderstanding of activities (particularly in the case of insecticide usage).

- Dilution of objectives: for example, subordinating the initial control objectives to other activities (as in RTTCP and FITCA).

Similarly, a range of factors can underlie the consequences of interrupted control activities, most particularly the suspension of monitoring procedures; by the time recrudescence is detected, the tsetse populations and trypanosomiasis transmission may already have returned to unacceptable levels. This in turn can affect national and international perception, such that many successful programmes may be described as failures when in fact they did not fail, but merely stopped. Again, such perceptions can affect the subsequent research agenda, since the perceived 'failure' will often be blamed on the techniques in order to stimulate research into 'new tools' (see Liese, Sachdeva & Cochrane, 1991).

An alternative approach is to specifically design an intervention programme to reach an end-point that is self-sustainable, i.e. is sustainable irrespective of change in future circumstances. The underlying concept is based on acceptance that the project cycle will end, that political priorities will change, and that civil unrest or other factors may lead to curtailment of the interventions, but that the advances made will nevertheless be irreversible.

6. ERADICATION STRATEGIES

6.1 BACKGROUND

In 1974, FAO was given a United Nations (UN) mandate to coordinate the eradication of tsetse and trypanosomiasis from Africa. In hindsight, this may seem over-ambitious given the technology then available, although advances were made, including development of PAAT (Programme Against African Trypanosomiasis), formally mandated by FAO, WHO, IAEA and the then OAU (now the African Union). PAAT[6] has been a useful forum for discussing ideas, compiling databases, and developing overall control strategies, although actual interventions have relied on national programmes and externally funded projects. Information from the PAAT information system suggests that tsetse control is currently being carried out over an aggregate of around 150 000 km^2 in various countries, including deployment of some 12 000 traps and 100 000 targets.

6.2 ERADICATION OF *G. AUSTENI* FROM ZANZIBAR

The campaign to eradicate *G. austeni* from the Island of Zanzibar (Unguja) was carried out partly for socioeconomic reasons – to improve livestock and agricultural productivity on the island – and partly as 'proof-of-principle' of an integrated approach to tsetse elimination using various means, including traps for initial population suppression, followed by SIT to complete the elimination of any remaining wild flies. The campaign was implemented during 1994-98 by the IAEA in partnership with the Governments of Zanzibar and Tanzania, with additional support from the International Fund for Agricultural Development (IFAD), the Organization of Petroleum Exporting Countries (OPEC) fund, and the Governments of Belgium, Canada, China, Netherlands, Sweden, UK and USA.

Unguja island covers an area of 1650 km^2; it has a mixture of agro-pastoral land and forest, including primary forest in the southern part (Jozani), and some 46 000 cattle and 26 000 sheep and goats. Prior to the campaign, annual losses due to tsetse and trypanosomiasis were estimated at around US$ 2 million. The tsetse suppression phase made use of cattle treatment using pour-on pyrethroid insecticides, together with some insecticide-impregnated blue cotton targets in the agro-pastoral regions. In Jozani forest however, high densities of such targets had to be deployed, typically 40-70 targets/km^2 (see section 3.2.3). Monitoring throughout the campaign was carried out using blue/white sticky panel traps at fixed sampling sites. A total of 8.5 million laboratory-reared sterile male flies were released by aircraft on fixed GPS-guided routes over the island (at an average of about 30 000 flies per week) from June 1994 to December 1997, even though no wild flies have been captured on the island since July 1996 (Dyck, 1998; Vreysen et al., 2000). According to unpublished IAEA reports, the Zanzibar campaign continues to be monitored, and no wild tsetse have since been encountered. The full costs of the campaign are not yet available. IAEA direct investment for 1995-97 (excluding staff) was US$ 539 578 (Dyck, 1998), although estimates by Hargrove (2003[a]) suggest a true cost nearer to US$ 850 000 – equivalent to around US$ 500 per km^2. Against this can be put the economic benefits to the Zanzibar community, which has now become a nett exporter of meat and dairy products (U. Feldmann, personal communication).

[6] http://www.fao.org/ag/againfo/programmes/en/paat/home.html

6.3 ISCTRC AND THE OAU

In October 1999, the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC), on the occasion of its 25th biannual meeting in Mombasa, Kenya, passed a recommendation on the necessity for African governments to give priority to tsetse and trypanosomiasis control. This was presented to the 36th summit meeting of the OAU in Lomé, Togo, July 2000. In response, the heads of state and government of the 36 OAU member states passed a historic resolution (Decision AHG/Dec.156 XXXVI) recognizing *"the seriousness of the problem as one of Africa's greatest constraints to socio-economic development.."* and calling on member states to *"act collectively to rise to the challenge of eliminating the problem.....to render Africa tsetse-free within the shortest time possible."* With this mandate, the OAU set up the Pan-African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC).

PATTEC was formally launched at the 26th ISCRTC meeting in Ouagadougou in October 2001, and its plan of action was formally endorsed by the OAU summits in Lusaka (OAU Decision AHG/Dec.169/XXXVII) and Durban (OAU/AU Decision CM/Dec.661/LXXVI 2002). The General Conferences of the FAO and IAEA adopted resolutions in support of this initiative[7], as did the World Health Assembly of WHO[8].

6.4 AU-PATTEC PLANS AND ACHIEVEMENTS

PATTEC was initially created as a programme within the OAU, but as of September 2003 it has been formally integrated into the African Union (AU) with a permanent secretariat under the AU Commissioner for Rural Development, required to report annually to the AU heads of state and government. It is essentially a political organization, designed partly to encourage African national authorities to implement the declared priorities of their heads of state with respect to tsetse elimination, partly to stimulate and mobilize additional support for implementation of these activities, and partly to facilitate international collaboration for tsetse control in areas where fly distribution is continuous across national borders. PATTEC is itself guided by an international policy committee (PATTEC-PMC) which meets annually under the AU Commissioner to discuss progress and set policy.

The PATTEC mandate encompasses the whole of sub-Saharan Africa where tsetse are endemic (Fig. 5). However, it is well recognized that it may not be feasible or necessary to eradicate all tsetse species and populations, and that not all regions are currently amenable to intervention. The PATTEC vision is of long-term activities, extending perhaps over 30-50 years, during which it is hoped that each target area will present a suitable 'window of opportunity' when political and economic stability permit large-scale intervention against tsetse and trypanosomiasis (Kabayo, 2002). No specific technical package is defined, since elimination of each target population will have its own technical requirements, and each target region will have its own background, experience, and practical capabilities. In general terms however, PATTEC promotes an implementation policy designed to select feasible intervention areas, suppress tsetse populations using any appropriate combination of trap and target deployment, insecticide-treated cattle, and/or SAT, to be followed by SIT if necessary for definitive elimination of the target population. Much depends on the ability to define feasible biological targets – i.e. tsetse populations that are either sufficiently biologically discrete that reinvasion would be unlikely, or that occupy regions around which effective barriers could be maintained until the neighbouring regions are also controlled – and to define these within a currently favourable political and economic regime that will permit the interventions to run their complete course.

[7] FAO 31st General Conference, Resolution No. 4/2001
IAEA 45th General Conference Resolution GC(45)/RES/12
IAEA 46th General Conference Resolution GC(46)/RES/11

[8] 56th World Health Assembly Resolution WHA56.7

FIG. 5 PATTEC MISSION

Objective
To implement the OAU-AU mandate to rid Africa of the burden of tsetse and trypanosomiasis in the shortest time possible

Methods
In partnership with African member states, national and international organizations, PATTEC seeks to achieve its objective in an integrated manner, with appropriate environmental monitoring, through an approach involving:

- Selection of feasible intervention areas
- Area-wide suppression of tsetse populations (mainly SAT, traps and targets, treated livestock, as appropriate)
- Monitoring of progress (traps and disease diagnosis)
- Maintenance of buffer zones to inhibit reinvasion
- SIT where feasible and necessary to complete local elimination
- Sequential expansion of treated areas to achieve progressive eradication.

Within this operational framework, PATTEC will also seek to support operational research, training and capacity building in each of the currently endemic areas, and to help organize emergency tsetse control interventions, especially in areas of new sleeping sickness epidemics.

Although PATTEC is still at an early stage, its plans and policies have been thoroughly reviewed and considerable progress has been made, most notably in reviving national programme policies in a number of countries (e.g. Mali, Nigeria, Uganda, S. Africa), placing tsetse and trypanosomiasis within formal 'poverty reduction' strategies (e.g. Ethiopia, Mali, Burkina Faso), and negotiating international accords for collaboration in tsetse elimination in several frontier regions. These international accords include:

- The cotton belt of Mali and Burkina Faso (planned also to include Ghana, Côte d'Ivoire and Sénégal)
- The Lake Victoria basin, including parts of Uganda, Tanzania and Kenya (planned also to include Rwanda)
- Ethiopia and southern Sudan
- The south-eastern tsetse pocket (*G. brevipalpis and G. austeni*) of southern Mozambique and KwaZulu Natal, South Africa
- The south-western fly belt (*G. m. centralis*) of Botswana, Namibia, western Zambia and southern Angola.

Most of these activities are focused primarily on elimination of cattle trypanosomiasis. However, WHO is formally represented on the PATTEC Policy Committee, and discussions are currently under way for collaborative activities in areas of active sleeping sickness transmission.

7. CONCLUSIONS

7.1 GENERAL CONCLUSIONS

- Cost estimates and DALY calculations for sleeping sickness have made it very clear that control of this disease is very cost-effective, due to the fatal outcome of the disease if untreated and to the focality of its distribution (TDR, 2003). Because of the huge economic costs of loss of livestock and draught animals, control of animal trypanosomiasis is paramount. However, the epidemiological complexity of the diseases, and the differing mandates of different institutions, means that international policies and efforts towards African trypanosomiasis control are fragmented. WHO focuses on surveillance and control of sleeping sickness and, through partnership with the pharmaceutical industry, has made available all the trypanocidal drugs free of charge. FAO and the EU focus on agricultural development, in which control of tsetse and trypanosomiasis is a relatively minor component. IAEA has strongly promoted large-scale tsetse control, but this is seen primarily as promotion of SIT as the main technique of interest. Only the OAU, now the AU, has embarked on a large-scale initiative to promote tsetse and trypanosomiasis control in an integrated manner, potentially leading to elimination of the trypanosomiasis problem.

- There is immense experience in the control of tsetse and trypanosomiasis. Much of this has been designed as research projects rather than operational campaigns, but the overall results have illustrated the vulnerability of tsetse and the susceptibility of trypanosomiasis to a range of control techniques. On the other hand, scrutiny of the various reports reveals that initial success was rarely maintained. Extensive prospective campaigns in West and Central Africa for example, designed to detect and treat all cases of gambiense sleeping sickness, have clearly not succeeded in eliminating the human infection, possibly due to greater involvement of reservoir hosts than had been realized. Furthermore, the devastating effects of civil disturbance and political strife, and the competing health priority needs in endemic countries, have contributed to the resurgence of sleeping sickness in the last 40 years. Similarly, tsetse control campaigns for animal trypanosomiasis – in some cases over several thousand km^2 – have generally not eliminated the flies except in areas close to their natural distribution limits, or on isolated islands. This history is variously interpreted by some as failure, and by others as transient success. Nevertheless, the range of techniques and approaches developed suggests that it is possible to tailor appropriate technical packages for control of tsetse and trypanosomiasis in any situation.

- There is now almost 100 years of experience and development of traps and targets for tsetse surveillance and control, and a range of designs and odour baits for different species of tsetse and different situations. Traps play a vital role in surveillance by monitoring apparent changes in tsetse abundance, while both traps and targets impregnated with biodegradable insecticides are a key component of tsetse control itself. Nevertheless, deployment of traps and targets alone is unlikely to achieve sustainable elimination of local tsetse populations, especially if deployed over limited areas without regard for the biological distribution limits of the target tsetse populations.

- Traps and targets can be deployed in different situations, according to the objectives of control. For HAT, whether in an epidemic or endemic situation, traps and/or targets should be deployed as an adjunct to case detection and treatment in order to reduce or interrupt transmission. Analysis of field data reveals that transmission is closely related to fly abundance, while field experience shows that traps can be effectively and economically deployed by communities with appropriate support and training. Moreover, involvement of the community in trap deployment is an important component of its engagement in the activities, and can encourage patient presentation and compliance with diagnosis and treatment programmes. Nevertheless, such measures should

be recognized as transient solutions only, since community and donor interest will wane once the problem is seen to be reduced; transmission is likely to resume after control measures are relaxed, even if infection only persists in a small proportion of the human population or in wild reservoir hosts.

7.2 IMPLEMENTATION RESEARCH NEEDS AND RECOMMENDATIONS

Odour baits
The efficiency of traps and targets is greatly enhanced by the addition of odour baits suitable for the particular set of target populations. Major advances have been made, and trap efficiency can be increased 2-10 times for some species. However, further work is warranted to develop improved odour baits, especially for flies of the palpalis and fusca groups. Improved odour-release systems designed to extend the time-course of odour attractiveness would also be helpful.

Colour fastness – phthalogen blue
The visual attractiveness of most traps and targets depends largely on the tsetse's orientation to blue colour, especially phthalogen blue, coupled with its landing response to black surfaces. One problem faced in long-term field deployment is colour fading, probably due to intense exposure to the sun, so that improved long-term UV stability in the dyes used would be helpful in extending the operational life of traps and targets.

Tsetse population genetics
Current approaches to tsetse control depend very largely on definition of the biogeographical limits of the target population in such a way that maximum benefit is gained from the natural barriers to reinvasion of the controlled areas. This requires investigating the genetic structure of the target populations in order to define the limits of panmixia, and using gene-flow models as surrogates for direct measures of tsetse dispersal. In addition, the techniques of population genetics, combined with adequate pre-control reference collections, can be applied to determine the likely source of any reinvading flies (i.e. whether apparent reinvasions are due to survivors of the original population, or are immigrants from untreated areas). Appropriate techniques have been well developed for American trypanosomiasis vectors (e.g. Dujardin et al., 2000) but are only beginning to be applied for tsetse (Solano et al., 1999; Krafsur, 2003). The TDR Scientific Working Group on African trypanosomiasis (TDR, 2003) identified as high priority the following areas of tsetse population genetics:

a) Development of DNA markers and their application to field-collected flies to understand the extent of genetic structuring in tsetse populations.

b) Investigation of mating incompatibilities existing among field populations.

c) Differences in vector competence of genetically isolated sub-populations of tsetse.

These recommendations are endorsed by this report. It is strongly recommended that further research on tsetse population genetics be promoted, including the application of geometric morphometrics as a less expensive surrogate to DNA sequence comparisons. Within this context, additional effort should also be made to develop adequate reference collections of tsetse (pinned and alcohol-preserved specimens) from all areas endemic for trypanosomiasis, against which further collections can be compared at morphometric and genetic level. All field collections should be georeferenced (e.g. using portable GPS systems) in order to benefit from advances in geographic information systems (GIS) databases of tsetse distribution[9] and determine the likely biogeographical limits of each genetically defined population. A research network, similar to that developed by the European

[9] http://ergodd.zoo.ox.ac.uk/tseweb/index.htm

Community – Latin American Network for Research on the Biology and Control of Triatominae (ECLAT) for American trypanosomiasis vectors[10], would possibly be the most effective approach to enable adequate sampling throughout the entire geographic distribution of target species.

Community participation

In view of the transient nature of community participation seen in the field, development of additional approaches to help sustain community interest in control programmes should be encouraged. In Uganda, for example, theatre has been used to encourage community interest (4.1.2), and, in Latin America, the epidemiology of American trypanosomiasis has been successfully introduced into the school curriculum in many regions.

Modelling of transmission recrudescence

Further theoretical work is recommended as a way to optimize trap and target deployment, in terms of both trap density and timescale of deployment, as a component of control of endemic or epidemic outbreaks of HAT. In addition, given the expected difficulties of sustaining long-term trap deployment, the models should seek to predict likely changes in future transmission rates given different scenarios of interruption of control efforts. In some areas, and in accordance with pre-existing prevalence rates in non-human reservoirs, it may be possible to indicate the future rates of recrudescence of transmission following relaxation of disease and vector control. This could indicate areas where additional control measures might be appropriate to reduce the risk of future transmission of human trypanosomiasis.

[10] http://ECLAT.fcien.edu.uy/

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