FORO

Prospects for area-wide integrated control of tsetse flies (Diptera: Glossinidae) and trypanosomosis in sub-Saharan Africa

Marc J.B. VREYSEN

Joint FAO/IAEA Programme of Nuclear Techniques in Food and Agriculture, Insect Pest Control Sub-programme, Department of Nuclear Sciences and Applications, International Atomic Energy Agency, Wagramerstrasse 5, A-1400 Vienna, Austria
m.vreysen@iaea.org

Perspectivas para el control integrado abarcativo del área de moscas tse-tsé (Diptera: Glossinidae) y la tripanosomiasis en el África sub-Sahariana

■ **RESUMEN.** Los países del África sub-Sahariana están entre los menos desarrollados del mundo, y el hambre y la pobreza continúan siendo muy extendidos en la mayoría de las comunidades rurales. Se considera que disminuir el hambre y la sub-alimentación mediante la introducción de ganado productivo, como fuente de tracción y abono para la producción agrícola, el transporte, los lácteos y la carne, es un primer paso fundamental hacia un mejor desarrollo rural. La presencia de la mosca tse-tsé en un tercio del continente africano y la tripanosomiasis que transmite, se consideran la principal barrera para el desarrollo del ganado productivo. A pesar de la administración anual de 35 millones de dosis de drogas tripanocidas (a 1 (un) dólar por dosis), los granjeros africanos pierden 3 millones de cabezas de ganado por año debido a esta enfermedad, y las pérdidas económicas directas se estiman entre 600 y 1200 millones de dólares. La mosca tse-tsé afecta principalmente a los campesinos pobres, y es considerada una causa fundamental de la pobreza en África. El método más deseable para reducir la tripanosomiasis es, sin duda, la eliminación de poblaciones enteras del vector en áreas geográficas delimitadas utilizando una combinación de varias tácticas de control, es decir, un enfoque del manejo de plagas integrado y abarcativo del área (AW-IPM, según sus siglas en inglés). Durante los últimos 50 años, se ha dispuesto de métodos eficientes para contener e incluso eliminar las poblaciones de mosca tse-tsé, mayoritariamente basados en el uso de insecticidas o incluyendo también dispositivos para atraer y matar. Sin embargo, y a pesar de los gigantescos esfuerzos realizados en el siglo pasado, sólo existen unos pocos ejemplos en los que la eliminación de moscas tse-tsé ha demostrado ser sostenible, por ejemplo, la eliminación de *Glossina pallidipes* Austen de Sudáfrica en la década de 1950, utilizando principalmente el rociado aéreo de insecticidas residuales; o la creación de una zona libre de *Glossina austeni* Newstead en la isla Unguja de Zanzíbar (1994-1997), mediante la integración de varias tácticas de control que incluyeron la liberación de insectos estériles. La descentralización de las oficinas de control de la mosca tse-tsé, que ocasionó un cambio de enfoques desde la erradicación a gran escala, hasta esfuerzos localizados de las comunidades agrícolas para controlar la mosca tse-tsé; y combinada con las crecientes crisis económicas y la inestabilidad política en muchos países africanos, contribuyó probablemente a la disminución de la mayoría de los esfuerzos para el control de la mosca en las últimas décadas. Es obvio que una erradicación sostenida en extensas áreas geográficas, redundaría en enormes beneficios para la comunidad agrícola rural. Los estudios genéticos de poblaciones de la mosca tse-tsé, y los datos obtenidos de sensores remotos satelitales están proporcionando evidencias cada vez más convincentes de que dichas poblaciones no se encuentran distribuidas en una zona continua (al menos en África Oriental), sino en grandes bolsones fragmentados. Estas «islas» de mosca tse-tsé (por ejempolo el Southern Rift Valley en Etiopía, KwaZulu Natal en Sudáfrica-Mozambique y el área de Niayes en Senegal Occidental), ofrecen excelentes oportunidades para la creación de zonas libres de dicha mosca, sustentable aplicando un enfoque AW-IPM.

PALABRAS CLAVE. Pobreza. Hambre. Zonas libre de mosca tse-tsé. Técnica de insectos estériles. Técnica secuencial de aerosol. Control de vectores.

■ **ABSTRACT.** Countries in sub-Saharan Africa are among the least developed in the world and hunger and poverty remains widespread in most of the rural communities. Reducing hunger and chronic under nourishment through the introduction of productive livestock as a source of traction and manure for crop production, transport, milk and meat is deemed to be a fundamental first step towards better rural development. The presence of the tsetse fly in one third of the African continent and the disease trypanosomosis it transmits is considered the major barrier to the development of productive livestock. Despite the yearly administration of 35 million doses of trypanocidal drugs (at US$ 1 per dose), African farmers lose 3 million cattle every year to the disease and annual direct economic losses are estimated at US$ 600 to 1200 million. Tsetse flies mainly affect the rural poor and are rightfully considered 'a root cause of poverty' in Africa. The most desirable way of containing the disease trypanosomosis is undoubtedly the elimination of entire populations of the vector from delimited geographical areas using an integration of various control tactics, i.e. an area-wide integrated pest management (AW-IPM) approach. Efficient methods to suppress or even eliminate tsetse populations have been available for the last 50 years and are mostly based on the use of insecticides or entail devices that attract and kill. Nevertheless, despite gigantic efforts in the past century, there are only a few examples where the elimination of tsetse flies has proven to be sustainable, e.g. the elimination of *Glossina pallidipes* Austen from South Africa in the 1950's using mainly aerial spraying of residual insecticides or the creation of a zone free of *Glossina austeni* Newstead on Unguja Island of Zanzibar (1994-1997) through the integration of various control tactics including the release of sterile insects. The decentralisation of the tsetse control offices resulting in a shift from large scale eradication approaches to localised tsetse control efforts by the local farmer communities, combined with the growing economic crises and political instability in many African countries has most likely contributed to the decline of most tsetse control efforts in the last decades. It is obvious that the sustained removal of the tsetse fly over large geographical areas would result in enormous benefits for the rural farmer community. Tsetse population genetic studies and data derived from satellite remote sensing are providing more and more convincing evidence that tsetse fly populations are not distributed in a continuous belt (at least in East Africa), but in large fragmented pockets. These tsetse 'islands' (e.g. the Southern Rift Valley in Ethiopia, KwaZulu Natal in South Africa-Mozambique and the Niayes area in West Senegal) offer excellent opportunities for the creation of sustainable tsetse-free zones using an AW-IPM approach.

KEY WORDS. Poverty. Hunger. Tsetse-free zones. Sterile insect technique. Sequential aerosol technique. Vector control.

1.Tsetse flies, hunger, poverty and rural development

Thirty four out of 49 African countries are classed as Least Developed Countries and can therefore be considered among the poorest in the world. Especially sub-Saharan Africa stands out in the developing world as the only region where the average food production per person has been declining over the past 40 years (UN, 2001). Nowhere is the proportion of the population living in extreme poverty (on less than US$ 1 per day) as high as in sub-Saharan Africa (UN, 2000a). Hunger, the most extreme manifestation of poverty, remains acute in rural sub-Saharan Africa with 34% of the population being under nourished. Alleviation of poverty can only start with the reduction of hunger and this can be achieved through the development of sustainable agricultural systems, in which livestock play a key role. Livestock not only provide milk and meat for nourishment and manure for fertilisation, but also are valuable in crop production, can act as security in terms of savings and hence, provide a vital source of income of the rural poor (Feldmann *et al.*, 2005). Productive livestock is however largely absent in the vast fertile areas of these countries, due to the omnipresence of an inconspicuous insect: the tsetse fly.

Tsetse flies, appropriately referred to by Nash (1969) as 'Africa's bane', are solely responsible for the cyclical transmission of trypanosomes, the causative agents of 'sleeping sickness' or Human African Trypanosomosis (HAT) in humans and 'nagana' or African Animal Trypanosomosis (AAT) in livestock. Although there are 31 different tsetse species and subspecies identified to date, only 8 to 10 of them are considered to be of economic (agricultural-veterinary) or human sanitary importance. Tsetse flies infest a total area of 9 million km^2 in sub-Saharan Africa (Fig. 1), exposing continuously 60 million people to the risk of infection. Only 3-4 million of these people are however covered by surveillance (WHO, 1998, Cattand *et al.*, 2001). Although the World Health Organization (WHO) estimates the disease prevalence at 300 000-500 000, this probably represents only 10-15% of the actual number infected (Cattand *et al.*, 2001) as screening is poor due to a decline in health service and surveillance coverage. In addition, civil unrest in various countries has resulted in a dramatic upsurge of the disease in the 1990's with 45 000 new cases being reported annually in 1998 and 1999. At the end of the 1990's, the infection rate in humans was back to where it was in 1930 (OAU/ISTRC, 1999). Due to increased surveillance and availability of drugs, a higher number of technicians trained and a bigger commitment of the international community in the last 5 years (2000-2005), the prevalence of HAT has declined and the situation seems to be more encouraging (report of WHO at the meeting of the International Scientific Council for Trypanosomiasis Research and Control (ISCTRC) in Addis Ababa, September 2005).

AAT is considered by many to be the single greatest health constraint to increased livestock production in sub-Saharan Africa with direct annual production losses in cattle estimated at US$ 600–1200 million (Hursey & Slingenbergh, 1995). Estimates of the overall annual lost potential in livestock and crop production have been as high as US$ 4750 million (Budd, 1999). Moreover, tsetse prevents the integration of crop farming and livestock keeping, which is crucial to the development of sustainable agricultural systems (Feldmann & Hendrichs, 1999). The lack of productive livestock, due to the presence of tsetse and trypanosomosis, is a key barrier in Africa to significantly improve agriculture. The removal of this barrier would be essential to the alleviation of hunger, food insecurity and poverty. The presence of tsetse and the disease they transmit can therefore rightfully be considered *a root cause of hunger and poverty* in sub-Saharan Africa. This is exemplified by the remarkable correlation and overlap between the 37 tsetse-infested countries and the 34 heavily indebted poor countries in Africa (Feldmann *et al.*, 2005). This link between tsetse, hunger and poverty is unfortunately not recognised by many decision makers, precisely because it is perceived as a problem of the rural poor (85% of the African poor are estimated to live in rural areas out of which 80% rely on agriculture for their livelihood (Mattioli et al., 2004)). Actions against this problem are only expected to provide results in the medium or long term, which is usually beyond the interest of many local politicians and/or international donors (Feldmann *et al.*, 2005). The lack of attention that the tsetse and trypanosomosis problem has been receiving is most noticeably shown through its absence in the World Bank and International Monetary Fund (IMF) commissioned Poverty Reduction Strategy Papers of many African nations (UN, 2000b, 2001).

2. Potential impact of tsetse control

Few will dispute the need for solving the tsetse and trypanosomosis problem and to create a breakthrough solution for the alleviation of hunger and poverty in Africa. This despite the attitude of some who claim that any initiative to eliminate tsetse from large parts of Africa is doomed to fail and therefore advocate the philosophy that the rural poor have to continue 'living with the problem' (Rogers & Randolph, 2002). It is obvious that AAT significantly impairs agricultural and rural development (Swallow, 1999) and some 45-50 million cattle live under permanent trypanosomosis risk (Shaw, 2004). Attempts to quantify the impact of the disease have taken into account the direct (mortality, fertility, milk production, animal traction and weight) and indirect effects on key productivity measures. Livestock kept under trypanosomosis challenge have a 6-20 percentage point higher annual calf mortality, a 6-19 percentage point lower calving rate and a 20% decrease in milk yield (Shaw, 2004). Weight loss and a reduction in work efficiency of oxen used to cultivate the land (up to 38%) are additional direct effects of the disease (Shaw, 2004). Untreated, the disease often becomes fatal. A series of indirect negative effects can exacerbate the situation, i.e. AAT impedes the use of productive exotic or cross-breeds of cattle; depresses the population growth of cattle;

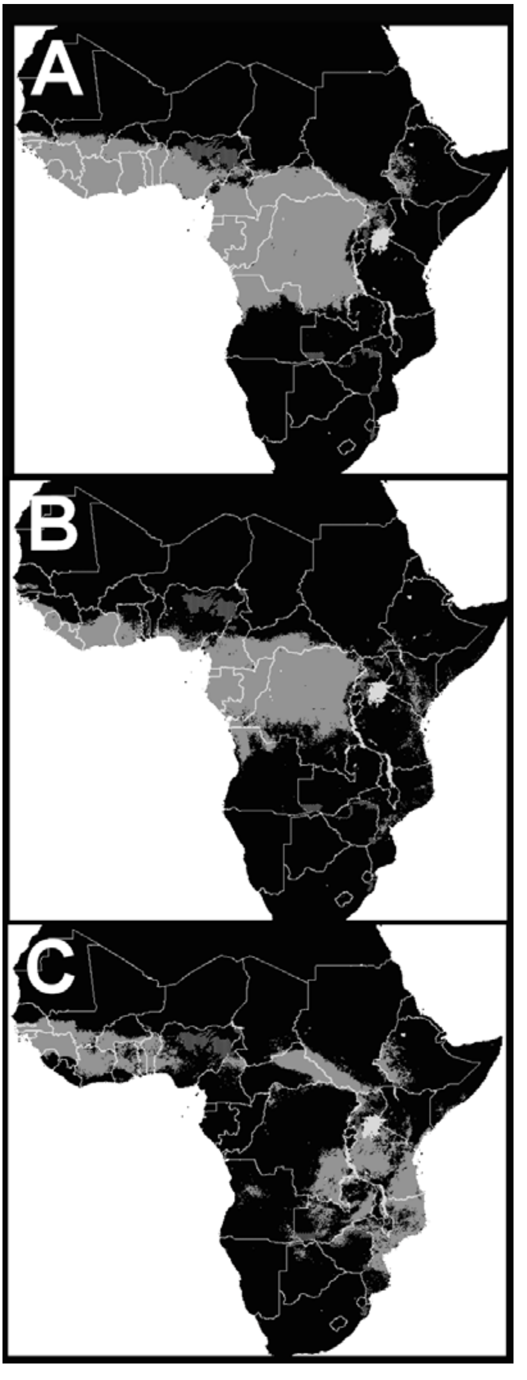

Figure 1. Distribution of the (A) *palpalis*, (B) *fusca* and (C) *morsitans* group of tsetse flies. (Maps produced by Environmental Research Group Oxford, reproduced with permission).

affects the distribution of livestock, herd size and structure; makes mixed farming impossible; affects human settlements and results in less draught power and less manure (Feldmann *et al,* 2005).

The removal of the tsetse fly will reduce the disease prevalence in livestock, mortality/ morbidity of domestic animals and the costs of treatments, i.e. it will result in generally improved livestock health and agricultural productivity. It will also result in the increased use of draught power which will result in an expansion of cropping. According to the dynamic herd model of Kristjanson *et al.* (1999), the benefits of enhanced trypanosomosis control, alone in terms of increased meat and milk production would be US$ 700 million per year. Although the number of cattle would increase under reduced trypanosomosis challenge, the creation of tsetse-free zones would stimulate the keeping of highly productive cross-breeds that can be kept at a lower average density than less productive breeds which would help preventing overgrazing.

3. Methods to contain the disease

There is a whole arsenal of control methods available that are suitable to tackle tsetse and the disease it transmits. They can be divided into methods to control the disease, the proliferation of trypanotolerant cattle and vector control.

3.1. Disease Control

The use of curative and prophylactic trypanocidal drugs, generally administered by the farmers themselves remains the most important method of controlling AAT in Africa today (Leak, 1998). In view of the absence of vaccines against trypanosomosis, the treatment of livestock with trypanocidal drugs is perceived as the most obvious and simple way of containing the disease. There are however, only 3 prophylactic and therapeutic drugs available (diminazene, isometamidium, homidium) of which an estimated 35 million doses are used every year (Holmes & Torr, 1988; Geerts & Holmes, 1998). These drugs are commonly available on the African market and their indiscriminate, unsupervised administration has given rise to increased levels of drug resistance of the parasite (Codjia *et al.*, 1993; Geerts & Holmes, 1998). Due to the high cost of developing new drugs and the relatively small commercial market, prospects for the development of new drugs in the near future remain slim (Leak, 1998).

3.2. Trypanotolerant cattle

The promotion of trypanotolerant cattle that show a certain degree of resistance to the disease has given encouraging results in areas of low trypanosomosis challenge. However, their small size and lack of strength to provide adequate draught power, has not made them very popular with livestock keepers (Hursey & Slingenbergh, 1995; Holmes, 1997). In addition, their distribution is mostly restricted to West Africa.

3.3. Tsetse control

Controlling the vector of the disease remains theoretically the most desirable way of containing the disease (Leak, 1998). Jordan (1986) shared the same view and stated that '*only by the removal of the tsetse fly can a disease-free environment be created*'. A broad gamut of vector control tools is available, which have all shown advantages and limitations. Some of the currently acceptable methods are based on the use of insecticides (the sequential aerosol technique), others on bait technologies (traps and targets, live bait technique), and others on genetics (sterile insect technique).

Sequential aerosol technique (SAT) - This method involves the ultra-low volume spraying of non-residual insecticides 10-15 m above the tree canopy by fixed wing aircraft or helicopter (in more difficult terrain) in 5-6 subsequent spraying cycles, separated by 16-

18 days depending on the temperature. The optimum droplet size needs to be sufficiently small to remain suspended long enough in the air rather than sinking to the ground, and large enough to prevent floating upwards. The goal is to kill all adult flies in the first spraying cycle by direct contact and then kill all emerging flies in the subsequent cycles before they can start reproducing. Although the technique is delicate (the insecticides have to be applied during periods of temperature inversion i.e. night time) and does not tolerate any delays in the timing of the cycles, it remains a perfect tactic (when using Global Position System (GPS)-guided navigation and spray systems) for effective area-wide tsetse suppression (in dense humid forest ecosystems) or even eradication (in open savannah-type ecosystems) (Allsopp & Hursey, 2004).

Stationary attractive devices - Stationary attractive devices, which largely replaced insecticide-spraying tactics in the 1990's, have the goal to attract female tsetse to an attractive device (traps and targets) that either kill the flies through tarsal contact with the insecticides embedded in the fabric or guide and collect the flies to a non-return cage. The method aims at exerting an additional daily mortality of 2-3% to the female segment of the population. Several technical aspects are essential for the efficient application of this bait technology such as appropriate trap/target site selection, adequate maintenance, periodic replacement and replenishment of the odours, appropriate reflectivity pattern of the used cloth, degradation of the insecticide deposits by UV light, etc. (Vreysen, 2001). The technique is suitable for deployment by the local farmer communities to protect small areas, but the high target densities required against certain species and in certain dense habitats make the use of these devices over large areas uneconomic (FAO, 1992; Kappmeier *et al.*, 2007).

Live bait technique - This method is based on the insecticide treatment of livestock and exploits the blood sucking behaviour of both sexes of tsetse. Tsetse flies, attempting to feed on cattle or other treated domestic livestock are killed by picking up a lethal deposit of insecticide on the ventral tarsal spines and on pre-tarsi whilst feeding (Leak, 1998). The success of the method depends on a relatively large proportion of feeds being taken from domestic animals (Gouteux, 1996) and a sufficient proportion of the livestock population being treated. The use of persistent insecticides on livestock has proven to have a suppressive effect on certain tsetse populations in those areas with a high density of cattle and where adequate expert support was present, e.g. in Zimbabwe against *G. pallidipes* Austen (Thomson & Wilson, 1992), in Burkina Faso against *Glossina morsitans submorsitans* Newstead and *Glossina palpalis gambiensis* Vanderplank (Bauer *et al.,* 1995) and against *Glossina fuscipes fuscipes* Newstead and *G. pallidipes* in Ethiopia (Leak *et al.*, 1995). Unlike with stationary attractive devices, the technique is less prone to theft and does not suffer from maintenance problems. However, several issues such as the required cattle density, the proportion of the herd that requires treatment, host preference of different tsetse species, etc. require further research. Other disadvantages are the high treatment frequency, the high cost of the insecticides, insecticide residues in cattle dung, motivation and participation of farmers and the potential development of resistance to the insecticides in both tsetse and ticks.

Sterile insect technique (SIT) - The SIT relies on the production of large numbers of the target insect in specialised production centres, the sterilisation of the males (or sometimes both sexes), and the sustained and systematic release of the sterile males over the target area in numbers large enough in relation to the wild male population to out-compete them for wild females. Mating of the sterile insects with virgin, native females will result in no offspring. With each generation, the ratio of sterile to wild insects will increase and the technique becomes therefore more efficient with lower population densities (inversely-density dependent). The SIT is non-intrusive to the environment, has no adverse effects on non-target organisms, is species-specific and can easily be integrated with biological control methods such as parasitoids, predators and pathogens. There is no development of resistance to the effects of the sterile males provided that adequate quality assurance is practised in the production process and the sterile insects cannot get established in the released areas as with other biological control programmes (Vreysen, 2001). The release of sterile insects is however only effective when the target population density is low, it requires detailed knowledge on the biology and ecology of the target pest, and the insect should be amenable to mass rearing. In addition, the SIT necessitates efficient release and monitoring methods, which have to be applied on an area-wide basis (Vreysen, 2005).

4. One hundred years of tsetse control: a shift in strategic thinking

Ever since man started exploring and cultivating the vast expanses of African land, they have been at war with the tsetse fly. With few exceptions, man has been on the defensive and in certain areas the fly even has expanded its territory (Vreysen *et al.*, 1999). During the last 100 years, the philosophy of approaching the tsetse and trypanosomosis problem has changed frequently. In the first half of the previous century, a very pragmatic attitude prevailed and efforts were aimed at eliminating those basic requirements, critical for the survival of tsetse, i.e. vegetation and host animals. These drastic measures of bush clearing and game destruction were very efficient and used with great success in certain areas of Zimbabwe, Zambia, Mozambique and Botswana. As an example, from 1946 to 1966, *G. m submorsitans* and *G. pallidipes* were eliminated from 20 000 km^2 in Uganda by the removal of wild host animals (Jordan, 1986). Increased environmental awareness and changing attitudes towards the preservation of biodiversity and wildlife combined with an increasingly lucrative tourist industry centred on game parks has made those practices unacceptable and obsolete.

The discovery of cheap, persistent organochlorine insecticides such as DDT (Dichlorodiphenyltrichloroethane), which became commercially available in 1945, marked the onset of the chemical warfare against the tsetse fly. The low production costs of DDT, its long persistence and high toxicity made it a cost effective and commercial success (Allsopp & Hursey, 2004). Four chemicals (DDT, dieldrin, endosulfan and deltamethrin) would dominate most tsetse control efforts for 40 years. They were initially mainly applied indiscriminatively (DDT and dieldrin) from the ground as residual (2-3 months) deposits. Later, concerns about bioaccumulation favoured more selective techniques that treated only the resting and breeding sites of the flies. This reduced cost, caused less environmental damage and was less demanding in terms of manpower as only a small percentage of the tsetse habitat was sprayed. Despite being very effective, the method was very labour intensive, required close supervision and planning and could only be applied during the dry season. The first example of the widespread use of persistent insecticides resulted in the elimination of the tsetse fly *G. pallidipes* from Zululand in South Africa in the 1940's. Using 6 aircraft in echelon formation, residual insecticides were sprayed from the air in a military style campaign supported by game destruction, bush clearing and extensive trapping. *G. pallidipes* was cleared from a total of 11 000 km^2 in 7 years (Du Toit, 1954) and Zululand remains to date a zone free of *G. pallidipes*. Similarly, between 1955 and 1978, 200 000 km^2 of tsetse-infested land was cleared in northern Nigeria, mainly by ground spraying. This tsetse control campaign, probably the most successful ever undertaken was extremely well organised with 5 operational spraying teams clearing tsetse from an average of 8000 km^2 each dry season. Each team consisted of 3 control officers, 6 assistants, 30 control assistants, 30 labourers and 300 casual labourers. To achieve this goal, a total of 745 metric tons of DDT and dieldrin were required (Jordan, 1986).

Spraying of residual insecticides was gradually replaced in the 1970-80's by the more environmental friendly sequential aerosol technique (SAT), that uses non-residual ultra-low volumes of insecticides (see section 3.3). The SAT was used successfully in Kenya, Zambia, Uganda, Botswana (Jordan, 1986) and in Zimbabwe, where 48 000 km^2 of savannah area were cleared from tsetse between 1981 and 1989 (Shereni, 1990). Most of these insecticide-spraying campaigns were very successful, especially when conducted at the edge of the tsetse belt. They were executed by centralised, well-funded tsetse control units/departments, which had no other responsibility but tsetse control and could rely on adequate entomological expertise. Institutional strength, adequate government support and national commitment aimed at eradication, was the common denominator of these operations.

The publication in 1962 of Rachel Carson's 'Silent Spring', which created a wave of anti-insecticide sentiment in the developed world, eventually influenced also the policy on tsetse control, both in Africa and elsewhere. Donors and national governments became gradually more reluctant to support tsetse control efforts that relied mainly on the use of insecticides. This was exacerbated by the general economic decline of many African countries after independence, the collapse of the veterinary departments, civil unrest and insecurity. As a result, the strategic thinking with respect to tsetse control shifted and more emphasis was placed on techniques that could be used by the farmer communities. The use of stationary and live bait techniques, i.e. the so-called 'low cost technologies' (although also insecticide-based), largely replaced the insecticide-spraying tactics in the 1990's. Because of the relatively low cost of its components and the perception of being 'unsophisticated', the use of traps and targets has been promoted in the last decades, especially by the donor community, as the most sustainable method of tsetse control.

The applications of these bait technologies entailed a shift from centralised to decentralised operations and were consequently not based on area-wide approaches and thus were less effective. Various sociological factors (e.g. theft, sustaining the interest of the farmers, willingness to contribute etc.), inaccessibility of riparian vegetation during the rainy season, destruction by fire, the absence of potent odour baits for some species and the very high target density required per km^2 in dense forest ecosystems, are factors affecting the efficiency of the farmer-based bait technology. Using this approach, tsetse populations were suppressed locally, provided expertise was available, supervision present, and seed money offered to buy the traps and insecticides. Despite the quick localised benefits that these programmes can bring to the farmers, they have to be implemented indefinitely and become therefore uneconomical in the long run (Vreysen, 2001). None of these control efforts proved sustainable (Barret & Okali, 1998) as is exemplified by the community-based efforts against human sleeping sickness in Ivory Coast (Laveissière *et al.*, 1985) or Uganda (Lancien, 1991), and against AAT in Nguruman, Kenya (Dransfield *et al.*, 1991) or Togo (Bastiaensen *et al.*, 2004).

The Government of Botswana was the first nation to accept the limitations of these stationary devices for large-scale operations and made a bold decision in 2000. Insecticides had been used since the 1960's, first by ground and between 1972 and 1991 by air against *G. morsitans centralis* Machado in the Okavango delta, the main tsetse focus in Botswana. After Botswana signed the Ramsar Convention (making the Okavango delta 'the largest wetland of international importance'), odour-baited targets (Vale *et al.*, 1988) replaced the aerial application of insecticides due to environmental concerns. This coincided by chance with the onset of a dry period, which lasted for 10 years and greatly facilitated the deployment of the 25 000 targets in the area. The programme was however severely disrupted in 1999 with the return of rains and severe flooding. The tsetse fly re-invaded cleared areas at an alarming speed and trypanosomosis re-appeared in cattle at the periphery of the delta. By 2000, the tsetse fly had expanded its territory to more than 11 000 km^2. This prompted the Botswana Government to readjust its tsetse control strategy and to revert back to aerial spraying. In 2001 and 2002, 7180 km^2 and 8722 km^2, respectively were treated with deltamethrin applied at a dose rate of 0.26 g/ha (Allsopp & Phillemon-Motsu, 2002). Deltamethrin is an insecticide safe to the environment that does not accumulate in the food chain and kills tsetse after a very brief contact (Leak, 1998). The spraying was carried out by a South African crop-spraying company, which used 4 aircraft equipped with efficient GPS-based SATLOCK guidance systems. The UK Department for International Development (DFID) undertook an environmental risk assessment and the Harry Oppenheimer Okavango Research Centre of the University of Botswana was contracted to coordinate a government-funded environmental monitoring programme. A private company of Australia took responsibility for the data management and statistical analysis of all biological components of the study. This environmental study indicated that both aquatic and terrestrial invertebrates recovered well after the spraying with populations of species of most families returning to pre-spraying abundances after one year (Perkins & Ramberg, 2004). The total cost of the spraying campaign was less than US$ 270/km^2 and although entomological monitoring has been quite limited, tsetse seemed to have disappeared from the sprayed areas. The 2001-2002 operation showed that i.) SAT is a rapid, efficient and cost effective method for tsetse elimination in the open savannah areas of East and Southern Africa. ii.) SAT does not have any serious lasting negative environmental impact, and iii.) it is cost effective to solicit foreign expertise when locally not available.

5. Advantages of area-wide integrated pest management (AW-IPM)

In the last 15-20 years, most tsetse programmes have focussed on the localised use of control tactics. While these cheap efforts were effective in temporarily alleviating the burden of trypanosomosis over very small areas, the *sustainable* removal of the tsetse fly will require control efforts directed against an *entire* tsetse population within a delimited geographical area (Klassen, 2005), i.e. the area-wide concept (e.g. in South Africa (du Toit, 1954) and on Unguja Island, Zanzibar (Vreysen *et al.*, 2000)). Models developed by Knipling (1972) indicated that uniform suppression of an *entire* population of an insect pest will achieve greater suppression than a higher level of control on most, but not all of the population, each generation.

AW-IPM differs from local pest management as i.) its focus is on preventive pest management before the pest population reaches damaging levels (whereas conventional methods react defensively only when the population has reached such levels), ii) it addresses all members of the pest population throughout the ecosystem (whereas conventional methods focus only on defending a valued entity (crop, livestock)), iii.) it requires several years of planning and an organisation dedicated exclusively to the control effort (whereas conventional methods only require minimal planning as they are implemented by individual farmers and therefore require no special organisation among farmers) and iv.) it tends to use advanced technologies such as geographic information systems (GIS), remote sensing and aerial release techniques (whereas conventional strategies employ 'low tech' tools that can be used by the farmer communities (Klassen, 2005)).

The release of sterile insects (SIT) against a number of insect pests of economic importance, including tsetse, is only effective when applied as part of an AW-IPM approach in view of the fact that mated wild females immigrating into localized control areas are immune to the presence of sterile males. The SIT was successfully integrated with other control tactics against livestock pests such as the New World Screwworm fly (Wyss, 2000; Lindquist *et al.,* 1999) and crop pests such as Lepidoptera (Henneberry, 2007; Bloem *et al.* 2005) and fruit flies (Cayol *et al.*, 2002). Initial studies in the 1960's in Zimbabwe and in the

1970's in Chad and Burkina Faso already indicated the potential of using the SIT against both riverine and savannah tsetse species (Dame and Schmidt, 1970; Cuisance & Itard, 1973; Van der Vloedt *et al.*, 1980). A first full-scale project was implemented from 1977 to 1979 and aimed at evaluating the SIT against the savannah species *Glossina morsitans morsitans* Westwood in a 195 km^2 test area in Tanzania. After suppression of the native tsetse population by two aerial applications of endosulfan, sterile males were released for 15 months at an average sterile to wild male ratio of 1.12:1. Despite this low ratio, sufficient sterility was induced in the native female population to maintain the population at 5% of the pre-control level (Williamson *et al.*, 1983).

This project was followed by two efforts in West Africa. From 1981 to 1984, two riverine species of tsetse, *G. palpalis gambiensis* and *Glossina tachinoides* Westwood were eliminated from 3500 km^2 of agro-pastoral land in Burkina Faso by integrating the release of sterile males with insecticide-impregnated screens. The release by ground of 35 sterile males/linear km of river resulted in average sterile to wild male ratios of 7:1, which induced sufficient sterility in the wild population to drive it to extinction (Politzar & Cuisance, 1984). In a similar effort in Nigeria (1979-1988), 1500 km^2 of agro-pastoral land was cleared from another riverine species, *Glossina palpalis palpalis* Robineau-Desvoidy using insecticide impregnated targets and traps followed by the release of sterile males at a ratio of 10 sterile to 1 wild male (Takken *et al.,* 1986; Oladunmande *et al.,* 1990). All these projects demonstrated that i.) the SIT is very effective against riverine and savannah tsetse, ii.) tsetse flies can be successfully mass-reared in Africa, iii.) a prolonged deployment of traps and targets in dense riverine vegetation does not lead to eradication, and iv.) none of these SIT-based projects were applied according to the area-wide concept and were therefore soon re-invaded by surrounding tsetse populations and thus not sustainable.

The first sustainable tsetse-free zone, using an AW-IPM approach with an SIT component, was created on Unguja Island, Zanzibar (1994-1997). The island, situated 35 km of the east-coast of Tanzania harboured only one species of tsetse, *Glossina austeni* Newstead. On average, 19% of the cattle were infected with mainly *Trypanosoma vivax* Ziemann and *Trypanosoma congolense* Broden. The direct losses caused by the disease to the livestock industry were estimated at US$ 2 million per year and 4000 head of cattle had to be imported every year to satisfy the demand in meat. The fly population was suppressed using the live bait technology in the agricultural zones of the northern half of the island (that had high cattle densities) and by the deployment of insecticide-treated blue cotton screens in the dense forested areas. Sterile male flies were dispersed first only over the southern half of the island and later over the entire surface area of Unguja Island (Vreysen *et al.,* 2000). The last indigenous tsetse fly was trapped in September 1996 and Unguja Island has remained free of tsetse and trypanosomosis ever since (Saleh *et al.*, 1999).

The success on Zanzibar created once again hope in Africa and incited African Governments to rethink their lost commitment to the tsetse and trypanosomosis cause. The African Heads of State and Government, at the 36th Ordinary Session of the Organization of African Unity (OAU) summit meeting in Lomé, Togo (July 2000) called for renewed efforts to control tsetse in Africa, which culminated in the establishment of the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC). The PATTEC initiative was approved at the OAU's meeting in Lusaka, Zambia in 2001 and officially launched in Ouagadougou, Burkina Faso later in the same year.

Analysis of old tsetse distribution data combined with remotely sensed satellite-derived data (Rogers *et al.*, 1996; Hay *et al.*, 1996) are giving more and more convincing evidence that the tsetse fly is not distributed along a continuous large belt in East Africa but rather in distinct pockets. This hypothesis is supported by data emanating from the analysis of gene frequencies of different populations of the same species (Krafsur, 2003). All these data strongly suggests that sustainable tsetse-free zones can be created on Africa mainland using area-wide management principles. Taking into consideration the view of the Food and Agriculture Organization of the United Nations (FAO) that the selection of priority areas for intervention should only be done in the context of sustainable agricultural development (Mattioli *et al.*, 2004), AW-IPM programmes should initially focus on those areas where it is technically feasible to create sustainable tsetse free zones and where the required investment results in maximum benefits. It is in that respect that excellent possibilities exist in Senegal, Ethiopia and South Africa, i.e. countries situated at the extreme limits of the tsetse distribution.

6. Senegal, Ethiopia and South Africa: Opportunities for the creation of tsetse-free zones using an AW-IPM approach

Senegal

The Niayes area, north of Dakar, is characterised by vestiges of Guinean gallery forest comprised of oil palms in low lying areas, which contain small marches. The area is inhabited by only one species of tsetse, *G. p. gambiensis*, which finds the ecological conditions in these areas favourable. The area is located at the extreme western limit of the tsetse distribution. The region has a coastal microclimate favourable to the rearing of exotic cattle breeds for milk and meat production. Tsetse fly was detected in 1971 and posed a serious risk of trypanosomosis transmission to the susceptible livestock and to humans. Until 1973, attempts were made to eradicate *G. p. gambiensis* from the Niayes using ground spraying with dieldrin. The fly was detected again in 1998 and surveys in 2003 suggested the isolated nature of the *G. p. gambiensis* population, which seems to be confined within a radius of 50 km from Dakar (S. Leak, unpublished report to the IAEA).

Initial population genetics studies revealed the complete absence of gene flow between the *G. p. gambiensis* population in the Niayes of Senegal and those of Mali (Marquez *et al.*, 2004). This study will be extended with flies sampled in the eastern part of Senegal and in the Gambia. In addition, the 2003 survey indicated that suitable habitat areas are very fragmented and degrading quickly through human activity. As such, the fly has adapted to peri-domestic habitats such as citrus orchards and vegetation surrounding market gardens (S. Leak, unpublished report to the IAEA).

The Government of Senegal has expressed interest in the removal of *G. p. gambiensis*, initially from the Niayes, and later from the entire country. In view of the apparent isolated nature of the fly population in the Niayes, the relatively small area infested, the high economic benefits that will emanate from the removal of the fly and trypanosomosis, the availability of a seed colony of the target species at the Centre International de Recherche-Développement sur l'Elevage en zone Subhumide (CIRDES) in Burkina Faso, the creation of a sustainable zone free of *G. p. gambiensis* using an AW-IPM approach, possibly with an SIT component, seems to have great potential.

Ethiopia

Ethiopia, a densely populated country of 67 million people, ranks among the poorest countries in Africa. More than 80% of the population has to rely on rural agriculture and livestock for survival, and agriculture accounts for 73% of the rural income. In rural areas, poverty exceeds 90% and an estimated 80% of the total population suffers from food insecurity. The situation is exacerbated by the presence of tsetse and trypanosomosis, which causes under-utilisation of much of the fertile agricultural lowlands, prevents a balanced exploitation of natural resources, denies opportunities for development and forces people to populate the fragile highlands. Over-exploitation of the land, soil degradation and depletion of natural resources are the logical consequences of this immense population pressure. The disease also constrains the use of oxen, which are the most important source of traction for the majority of farmers. Four economically important species of tsetse (*G. pallidipes*, *G. tachinoides*, *G. m. submorsitans* and *G. fuscipes fuscipes*) inhabit the south-western

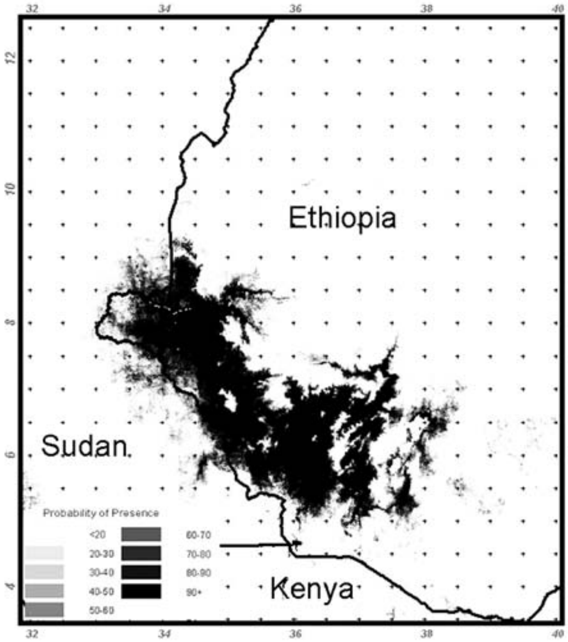

Figure 2. Presence-absence prediction model indicating the probability of presence of the tsetse species *Glossina pallidipes* in Ethiopia. (Map adapted from a prediction model produced by Environmental Research Group Oxford)

part of the country in an area larger than 150 000 km^2. More than 10 million cattle are permanently at risk of contracting tsetse transmitted trypanosomosis.

The Federal Government of Ethiopia has acknowledged that the tsetse and trypanosomosis problem in these south-western valleys is a major constraint for the reduction of poverty, improved food security and for sustainable agriculture and rural development. The international community, i.e. the African Union Inter-African Bureau for Animal Resources (AU-IBAR), the Programme Against African Trypanosomiasis (PAAT), PATTEC, the FAO and the IAEA have endorsed a 25 000 square km. project zone in the Southern Rift Valley as a priority for integrated area-wide control of the tsetse fly.

An entomological survey in 10 000 km^2 of this valley, initiated in 1998, indicated that *G. pallidipes* was widespread, present at high population densities in certain areas and had extended its distribution by 200 m in altitude (up to 1990 m) and 100 km northwards as compared to 25 years ago (Vreysen *et al.*, 1999). A second species, *G. f. fuscipes* was sampled in the river systems of 12% of the surveyed grids and was confined to the western part of the area. The spatial distribution of the tsetse fly population correlated well with that of the disease. These base-line data have been instrumental for the development of a selective monitoring programme (Vreysen, 2000) and of a control strategy. The strategy aims at suppressing the tsetse population using insecticide-impregnated targets in areas with human settlements, the live bait technology in areas with sufficient livestock and the SAT in the un-inhabited areas. In the final phase of the AW-IPM strategy, sterile males will be released in those areas where the flies persist at low densities.

To address the SIT component, the Federal Government of Ethiopia has established a temporary insectary, where a seed colony of *G. pallidipes* has been initiated with biological material collected in the target area. In addition, construction of a modular mass-rearing facility has been initiated in Addis Ababa that is foreseen to maintain a colony of 10 million producing female tsetse. This could ensure a weekly output of one million sterile males, which, at a dispersal rate of 100 sterile males per km^2, could cover a total area of 10 000 km^2.

The creation of a tsetse-free zone in the Southern Rift Valley, followed by the potential removal of all tsetse populations from the other Ethiopian valleys is undoubtedly technically feasible with the currently available control methods. It is anticipated that area-wide control tactics such as SAT and SIT will play an important role. The Ethiopian tsetse belt (with a small extension into Sudan), although vast at 150 000 km^2, is completely isolated from the remainder of the fly belt in East Africa. This makes the removal of tsetse from the Ethiopian territory once and for all an attractive but real possibility (Fig. 2). Moreover, the tsetse is confined to reasonably isolated valleys that could be treated in sequence as separate populations according to the 'rolling carpet principle' (Hendrichs *et al.*, 2005). According to this concept, the entire control area is divided into various intervention blocks and the size of each block will depend on logistics, the sterile insect production capacity and topographical characteristics of the area. Each of the basic operational phases (pre-intervention, population reduction, releases of sterile insects) are carried out simultaneously in a phased manner. Areas cleared of tsetse will be protected from reinvasion by the moving suppression front, where fly populations are being reduced. Where needed, temporary buffer zones can be erected to consolidate the progress made (Hendrichs *et al.*, 2005). It is obvious that the sustained removal of tsetse from the Southern Rift Valley will result in enormous economic benefits and the Government of Ethiopia remains highly committed to this project. However, problems with the mass-rearing of the target tsetse *G. pallidipes*, shortage in local entomological expertise in the various components of AW-IPM in general and SIT in particular, the reluctance to accept foreign expertise as a government policy, and the absence of an independent, flexible management structure (Vreysen *et al.*, 2007) will make this programme a very challenging one.

South Africa

South Africa has a long history of livestock problems associated with animal trypanosomosis and tsetse control. As an example, after a large outbreak of AAT in 1929, 27 000 wild host animals were culled in and around the Umfulozi game reserve in KwaZulu Natal that, together with the deployment of 12 000 Harris traps (Harris, 1938), brought the outbreak under control (Kappmeier *et al.*, 1998). After the elimination of *G. pallidipes* from Zululand in 1952 (Du Toit, 1954), no significant problems with trypanosomosis were encountered in South Africa, aside from some isolated cases (Bagnall, 1993). Trypanosomosis became 'a forgotten problem' until in 1990, 10 000 cattle died in KwaZulu Natal as a result of an outbreak of AAT (Kappmeier *et al.,* 1998). An emergency programme, consisting mainly of a rigorous scheme of dipping cattle with insecticides, brought the outbreak under control. The outbreak was mainly attributed to the presence of *G. austeni* and *Glossina brevipalpis* Newstead, which, until then were considered of minor importance as transmitters of the disease. The 1990-outbreak undermined this assumption and the Onderstepoort Veterinary Institute was contracted to develop a long-term tsetse control strategy (Kappmeier *et al.*, 1998).

A feasibility study was initiated to assess whether a sustainable solution to the tsetse and trypanosomosis problem in South Africa could be found through the creation of a tsetse-free zone (Kappmeier *et al.,* 2007). As a first step, a new sampling device (i.e. the H-trap) was developed that could sample both tsetse species in adequate numbers (Kappmeier, 2000). This was especially challenging for *G. austeni* in view of their reluctance to enter tsetse traps that are efficient for other tsetse species. This was followed by entomological field surveys to determine the distribution of *G. austeni* and *G. brevipalpis*. The resulting field data were used to develop a satellite-derived 'Probability of Presence' model which confirmed that both species are confined to isolated areas that are restricted to north-eastern KwaZulu Natal with the exception of a small extension into Mozambique (AVIA-GIS, 2000).

Secondly, an evaluation of various tsetse suppression methods indicated that the SAT is probably the best method for suppression, possibly even eradication in certain open areas, of the two species in the natural and commercial game areas. The use of insecticide-treated targets was considered to be impractical for use on a large scale in view of the required high target densities (8-12 targets/km^2 for *G. brevipalpis*) and might be considered only for localised use in areas where SAT application is not possible. In the communal and commercial livestock farming areas, insecticide-treated cattle may be the most practical option as KwaZulu Natal has well-developed functional dip facilities (Kappmeier *et al.,* 2007). In view of the topography and the dense vegetation in certain areas, the release of sterile male tsetse will most likely be needed as a final component of the AW-IPM approach. Membrane-adapted colonies of *G. brevipalpis* and *G. austeni* have been initiated at the Onderstepoort Veterinary Institute to provide the necessary seed material for the initiation and build-up of large tsetse colonies. Discussions are underway to explore the possibilities to develop a large tsetse mass-rearing factory in South Africa.

The available data emanating from these preparatory studies indicates that creating a zone free of *G. austeni* and *G. brevipalpis* in South Africa using an SIT-based AW-IPM approach is feasible. The proposal suggests the division of the total tsetse-infested area of KwaZulu Natal, which comprises ca. 12 000 km^2, into 4 zones, which could be addressed sequentially. Each project phase would include pre-suppression activities, suppression, eradication and post-eradication operations and each of these phases would be implemented successively in the four zones according to the 'rolling carpet principle' (Hendrichs *et al.,* 2005). It is estimated that 6 years of operational programme implementation will be needed to eliminate both tsetse species from KwaZulu Natal and Southern Mozambique (Kappmeier *et al.*, 2007).

A socio-economic study indicated that significant economic benefits would emanate from an area-wide tsetse eradication effort in KwaZulu Natal with a breakeven point reached during the 8th year. A cumulative total net benefit (net present value, taking into account a discount rate of 8%) of US$ 51 million and an overall benefit to cost ratio of 3.4 would be obtained over a 15-year time frame, not taking into account additional benefits, such as improved agricultural productivity due to improved health of draft animals. As from year nine, the project reaches the maintenance phase and benefits will be fully established; the annual benefit to cost ratio fluctuates from 90-493 per US$ invested (year nine to year 15). Moreover, the project has an internal rate of return of 23%, meaning that the discount rate could be almost three times higher than the estimated value of 8% and the project would still break even in a 15-year time frame (Jon Knight, unpublished report to the IAEA; Kappmeier *et al.*, 2007).

This tsetse situation is very unique, which makes the creation of a South Africa free of tsetse an attractive long-term solution to the AAT problem. The area has high agricultural potential, is situated at the southern limit of the tsetse belt, has a technically manageable size, has only 2 species of tsetse that are already adapted to artificial rearing conditions and can be divided in 4 fairly isolated blocks that can be treated sequentially. The area extends only for about 25-50 km into Mozambique, but the total infested zone is completely isolated from the rest of the tsetse belt in Mozambique.

7. Conclusions

Past tsetse control efforts have clearly demonstrated that *sustainable* tsetse-free zones can be created on mainland Africa, using a variety of available tsetse control tactics. A common denominator of these successful programmes was a strategy directed against an entire tsetse population (area-wide). An important distinction needs to be made between localised tsetse control efforts to temporarily solve a critical disease crisis in a rural community and a centralised programme to create a sustainable tsetse-free zone. Both approaches have merit but are driven by completely different goals and entail different requirements. This distinction is often not appreciated or respected by opponents and proponents of either approach.

Aiming for and adopting an AW-IPM approach, that probably will result in better long-term and more sustainable control is, however, by itself no guarantee for success. Especially, programmes that include an SIT component are very management intensive, technically complex with many interdependent components. These programmes cannot be successful without fulfilling certain technical (e.g. the availability of high quality base-line data, optimal competitiveness and mating compatibility of the strain used for release, a sound monitoring component) and managerial prerequisites (e.g. a flexible and independent management structure, dedicated full-time staff, consistency in the implementation of critical programme components, commitment of all stakeholders, adequate funding (Vreysen *et al.*, 2007)).

The programmes in Tanzania, Nigeria, Burkina Faso and Zanzibar, which all had a prominent SIT component have demonstrated the effectiveness of the release of sterile males against both savannah and riverine tsetse species. However, SIT should not be considered as 'the panacea that will succeed where other methods have failed'. The SIT should rather be used judiciously in those topographical and ecological situations where the technology can make a difference, e.g. to eliminate relic pockets or against those species that are confined to humid, dense vegetation ecosystems like *G. f. fuscipes* or the riverine species in West Africa, where other control tactics are less successful to deal with the last remnants of tsetse populations. The recent successful application of the SAT in Botswana has provided ample evidence that the SAT is extremely suitable to tackle tsetse in flat, open, woody savannah areas without having the negative environmental impact that many environmentally conscious people like to proclaim. An extensive post-spraying monitoring campaign is however needed to confirm eradication. If residual relic pockets were to be exposed, data should be collected to help in the decision-making process whether SIT could or should be applied.

It is important that lessons be learned from past successful control efforts and failures to avoid repeating historical mistakes. We believe that there is reason for optimism in view of the current new political initiatives to revive tsetse control efforts, but there is likewise a need to focus, to ensure adequate funding and to solicit appropriate technical and managerial expertise. National governments and the donor community have to be made aware that addressing the tsetse and trypanosomosis problem requires a long-term commitment and that sound partnerships with national institutes and international organisations are essential. Obviously, there are reasons for concern and unstable national governments, pervasive corruption, warfare, social unrest and institutional conflicts are certainly major obstacles to the effective implementation of area-wide eradication programmes. As discussed in this paper, several potential areas in mainland Africa have been identified where the creation of sustainable tsetse-free zones is deemed possible using an AW-IPM approach. The economic benefits emanating from the removal of tsetse will be substantial for the livestock keepers and therefore, these opportunities should not be missed.

LITERATURE CITED

1. ALLSOPP, R. & T. K. PHILLEMON-MOTSU. 2002. Tsetse control in Botswana – a reversal in strategy. *Pest. Outlook* 13: 73-76.
2. ALLSOPP, R. & B. H. HURSEY. 2004. Insecticidal control of tsetse. *In*: Maudlin, I., P. H. Holmes & M. A. Miles (eds.), *The Trypanosomiasis*, Cabi publishing, Oxfordshire, UK, pp. 491-507.

3. AGRICULTURE AND VETERINARY INTELLIGENCE AND ANALYSIS (AVIA-GIS). 2002. *Tsetse presence-absence prediction model for* Glossina austeni *and* Glossina brevipalpis *in KwaZulu Natal – South Africa.* Report to the International Atomic Energy Agency. IAEA, Vienna, Austria.

4. BAGNALL, R. J. 1993. Trypanosomosis in Zululand. *In: Proc.24th Meeting of the SARCCUS Standing Committee for Animal Health*, Mbabane, Swaziland. pp. 41-49.

5. BASTIAENSEN, P., N. T. KOUAGOU, M. GNOFAM, K. BATAWUI, A. NAPALA & G. HENDRICKX. 2004. Adoption d'une nouvelle technique de contrôle de la mouche tsétsé par des éleveurs du nord du Togo: considerations socio-économiques. *Bull. Anim. Hlth. Prod. Afr.* 52: 142-158.

6. BARRET, K. & C. OKALI. 1998. Partnerships for tsetse control – community participation and other options. *World Animal Rev.* 90 (1998/1): 39-46.

7. BAUER, B., S. AMSLER-DELAFOSSE, P-H. CLAUSEN, I. KABORE & J. PETRICH-BAUER. 1995. Successful application of deltamethrin pour-on to cattle in a campaign against tsetse flies (Glossina spp.) in the pastoral zone of Samorogouan, Burkina Faso. *Trop. Med. Parasitol.* 346: 183-189.

8. BLOEM, K. A., S. BLOEM, & J. E. CARPENTER. 2005. Impact of moth suppression/eradication programmes using the sterile insect technique or inherited sterility. *In*: Dyck, V. A., J. Hendrichs & A. S. Robinson (eds.). *Sterile Insect Technique. Principles and Practice in Area-wide Integrated Pest Management*, Springer, Dordrecht, The Netherlands, pp. 677-700

9. BUDD, L.T. 1999. *DFID-funded tsetse and trypanosomiasis research and development since 1980. Volume 2 – economic analysis.* Department of International Development, UK.

10. CARSON, R. 1962. *Silent spring*. Houghton Mifflin Company, Boston, USA.

11. CATTAND, P., J. JANNIN & P. LUCAS. 2001. Sleeping sickness surveillance: An essential step towards elimination. *Trop. Med. Int. Health.* 6: 348-361.

12. CAYOL, J. P., J. HENDRICHS, W. ENKERLIN, A. DYCK & M. VREYSEN. 2002. The sterile insect technique: an environment friendly method for the area-wide integrated management of insect pests of economic significance, *In*: *Proceedings, 2nd International Conference on the Alternative Control Methods against Plant Pests and Diseases*, 4–7 March 2002, Lille, France. INRA, France. pp. 593–600.

13. CODJIA, V., M. WOUDYALEW, P. A. O. MAJIWA, S. G. A. LEAK, G. J. ROWLANDS, E. AUTHIE, G. D. M. d'IETEREN & A. S. PEREGRINE. 1993. Epidemiology of bovine trypanosomosis in the Ghibe valley, southwest Ethiopia. 3. Occurrence of populations of *Trypanosoma congolense* resistant to diminazene, isometamidium and homidium. *Acta Trop.* 53: 151-163.

14. CUISANCE, D. & J. ITARD. 1973. Comportement de mâles stériles de *Glossina tachinoides* West. lâchés dans les conditions naturelles – environs de Fort-Lamy (Tchad). I. Transport, lâchers, rythme d'activité, action sur la population sauvage. *Revue Élev. Méd. Vét. Pays Trop.* 26: 55–76

15. DAME, D. A. & C. H. SCHMIDT. 1970. The Sterile Male Technique against Tsetse Flies, Glossina sp. *Bull. Entomol. Soc. Am.* 16: 24-30.

16. DRANSFIELD, R. D., B. WILLIAMS & R. BRIGHTWELL. 1991. Control of tsetse flies and trypanosomiasis: myth or reality. *Parasitology Today* 7: 287-291.

17. DU TOIT, R. 1954. Trypanosomiasis in Zululand and the control of tsetse flies by chemical means. *Onderstepoort J. Vet. Res.* 26: 317-387.

18. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO). 1992. *Use of attractive devices for tsetse survey and control.* Training manual for tsetse control personnel, Volume 4, FAO, Rome.

19. FELDMANN, U. & J. HENDRICHS. 1999. The concept for integration of the sterile insect technique as a key component of future sub-regional area-wide tsetse and trypanosomosis management operations. *In*: *Animal Trypanosomosis: Vector and Disease Control using Nuclear Techniques*, Backhuys Publishers, Leiden, The Netherlands, pp. 191-214.

20. FELDMANN, U., V. A. DYCK, R. C. MATTIOLI & J. JANNIN. 2005. Potential impact of tsetse fly control involving the sterile insect technique. *In*: Dyck, V. A., J. Hendrichs & A. S. Robinson (eds.), *Sterile insect technique. Principles and practice in area-wide integrated pest management.* Springer, Dordrecht, The Netherlands, pp. 701-726.

21. GEERTS, S. & P. H. HOLMES. 1998. *Drug management and parasite resistance in bovine trypanosomosis in Africa.* PAAT position paper, FAO, Rome.

22. GOUTEUX, J. P., F. Le GALL, J. M. GUILLERME & D. DEMBA. 1996. Traitement épicutané (Pour on et Spot on) du bétail contre *Glossina fuscipes fuscipes* en République Centrafricaine. *Vet. Res.* 27: 273-284.

23. HARRIS, R. H. T. P. 1938. The control and possible extermination of the tsetse by trapping. *Acta Conv.ter Trop. Malar. Morb. Pars.*1: 663-677.

24. HAY, S. I., C. J. TUCKER, D. ROGERS & M. J. PACKER. 1996. Remotely sensed surrogates of meteorological data for the study of the distribution and abundance of arthropod vectors of disease. *Ann. Trop. Med. Parasitol.* 90: 1-19.

25. HENDRICHS, J., M. J. B. VREYSEN, W. R. ENKERLIN & J. P. CAYOL. 2005. Strategic options in using sterile insects for area-wide integrated pest management, *In:* Dyck, V. A., J. Hendrichs & A. S. Robinson (eds.), *Sterile insect technique. Principles and practice in area-wide integrated pest management.* Springer, Dordrecht, The Netherlands. pp. 563-600

26. HENNEBERRY, T. J. 2007. Integrated systems for control of the pink bollworm in cotton. *In:* Vreysen, M. J. B., A. S. Robinson & J. Hendrichs (eds.), *Area-wide Control of Insect Pests: From Research to Field Implementation*, Springer, Dordrecht, The Netherlands (in press).

27. HOLMES, P. H. 1997. New approaches to integrated control of trypanosomosis. *Vet. Parasit.* 71: 121-135.

28. HOLMES, P. H. & S. J. TORR. 1988. The control of African Trypanosomiasis in Africa: Current methods and future trends. *Outlook on Agriculture* 17: 54-60.

29. HURSEY, B. S. & J. SLINGENBERGH. 1995. The tsetse fly and its effects on agriculture in sub-Saharan Africa. *World Animal Rev.* 84-85: 67-73.

30. JORDAN, A.M. 1986. *Trypanosomiasis control and African rural development.* Longman Group Ltd, England.

31. KAPPMEIER, K. 2000. A newly developed odour-baited «H trap» for the live collection of *Glossina brevipalpis* and *G. austeni* (Diptera: Glossinidae) in South Africa. *Onderstepoort J. Vet. Res.* 67: 15-26.

32. KAPPMEIER, K., E. M. NEVILL & R. J. BAGNALL. 1998. Review of tsetse and trypanosomosis in South Africa. *Onderstepoort J. Vet. Res.* 65: 195-203.

33. KAPPMEIER GREEN, K., F. T. POTGIETER & M. J. B. VREYSEN. 2007. A strategy for an area-wide control campaign with an SIT component to establish a tsetse-free South Africa. *In:* Vreysen, M. J. B., J. Hendrichs & A. S. Robinson (eds.)*, Area-wide Control of Insect Pests: From Research to Field Implementation*, Springer, Dordrecht, The Netherlands (in press).

34. KNIPLING, E. F. 1972. Entomology and the management of man's environment. *J. Austr. Entomol. Soc.* 11: 153–167.

35. KLASSEN, W. 2005. Area-wide integrated pest management and the sterile insect technique. *In*: Dyck, V.A., J. Hendrichs & A. S. Robinson (eds.), *Sterile insect technique. Principles and practice in area-wide integrated pest management.* Springer, Dordrecht, The Netherlands. pp. 39-68.

36. KRAFSUR, E. S. 2003. Tsetse fly population genetics: an indirect approach to dispersal. *Trends Parasitol.* 19: 162–166.

37. KRISTJANSON, P. M., B. M. SWALLOW, G. J. ROWLANDS, R. L. KRUSKA & P. N. DE LEEUW. 1999. Measuring the cost of African animal trypanosomosis, the potential benefits and returns to research. *Agr. Systems* 59: 79-98.

38. LANCIEN, J. 1991. Lutte contre la maladie du sommeil dans le sud-est Ouganda par piégeage des *Glossines. Ann. Soc. belge Méd. Trop.* 71: 35-47.

39. LAVEISSIERE, C., J. P. HERVOUET, D. COURET, J.-P. EZOUAN & F. MEROUZE. 1985. La campagne pilote de lutte contre la trypanosomiase humaine dans le foyer Vavoua (Côte d'Ivoire). 2. La mobilisation des communautés rurales et l'application du piégeage. *Cah. ORSTOM sér. Ent. Méd. et Parasitol.* 23: 167-185.

40. LINDQUIST, D. A., M. ABUSOWA & M. J. R. HALL. 1999. The New World Screwworm fly in Libya: a review of its introduction and eradication. *Med. Vet. Entomol.* 6: 2-8.

41. LEAK, S. G. A. 1998. *Tsetse biology and ecology: their role in the epidemiology and control of trypanosomosis.* Cabi publishing, Wallingford, UK.

42. LEAK, S. G. A., W. MULATU, G. J. ROWLANDS & G. D. M. D'IETEREN. 1995. A trial of a cypermethrin 'pour-on' insecticide to control *Glossina pallidipes, G. fuscipes fuscipes* and *G. morsitans submorsitans* (Diptera: Glossinidae) in Southwest Ethiopia. *Bull. Entomol. Res.* 85: 241-251.

43. MARQUEZ, J. G., M. J. B. VREYSEN, A. S. ROBINSON, S. BADO & E. S. KRAFSUR. 2004. Mitochondrial diversity analysis of *Glossina palpalis gambiensis* from Mali and Senegal. *Med. Vet. Entomol.* 18: 288-295.

44. MATTIOLI, R. C., U. FELDMANN, G. HENDRICKX, W. WINT, J. JANNIN & J. SLINGENBERGH. 2004. Tsetse and trypanosomiasis intervention policies supporting sustainable animal-agricultural development. *Food, Agr. Environ.* 2: 310-314.

45. NASH, T. A. M. 1969. *Africa's Bane: the Tsetse Fly.* Collins, London, UK.

46. OLADUNMADE, M.A., U. FELDMANN, W. TAKKEN, S. O. TENABE, H.-J. HAMANN, J. ONAH, L. DENGWAT, A. M. V. VAN DER VLOEDT & R. E. GINGRICH. 1990. Eradication of *Glossina palpalis palpalis* (Robineau-Desvoidy) (Diptera: Glossinidae) from Agropastoral land in central Nigeria by means of the sterile insect technique. In: *Sterile Insect Technique for Tsetse Control and Eradication - Proceedings Final Research Coordination Meeting, Vom, Nigeria, 6 - 10 June, 1988.* IAEA/RC/319.3/1: 5-23

47. ORGANIZATION OF AFRICAN UNITY / INTERNATIONAL SCIENTIFIC COUNCIL FOR TRYPANOSOMIASIS RESEARCH AND CONTROL (OAU/ISCTRC). 1999. Meeting report of the twenty-fifth meeting of the, Mombassa, Kenya. Tsetse and Trypanosomiasis Information Quarterly 22: 163-164.

48. PERKINS, J. S. & L. RAMBERG. 2004. *Environmental recovery monitoring of tsetse fly spraying impacts in the Okavango delta – 2003.* Okavango report series no. 3. Harry Oppenheimer Okavango Research Centre, University of Botswana. pp. 157.

49. POLITZAR, H. & D. CUISANCE. 1984. An integrated campaign against riverine tsetse, *Glossina palpalis gambiensis* and *Glossina tachinoides*, by trapping and the release of sterile males. *Insect Sci. Applic.* 5: 439-442.

50. ROGERS, D. J. & S. E. RANDOLPH. 2002. A response to the aim of eradicating tsetse from Africa. *Trends Parasitol.* 18: 534-536.

51. ROGERS, D., S. I. HAY & M. J. PACKER. 1996. Predicting the distribution of tsetse flies in West Africa using temporal Fourier processed meteorological satellite data. *Ann. Trop. Med. Parasitol.* 90: 225-241.

52. SALEH, K. M., W. A. MUSSA, K. G. JUMA & M. J. B. VREYSEN. 1999. Eradication of *Glossina austeni* from the island of Unguja confirmed: results of 2 years of post-eradication monitoring activities. *In*: *25 th meeting of the International Scientific Council for Trypanosomiasis Research and Control*, Mombasa, Kenya, 27 September - 1 October, 1999, OAU/STRC, Nairobi, Kenya. pp. 231-238.

53. SHAW, A.P.M. 2004. Economics of African trypanosomiasis. *In:* Maudling, I., P. H. Holmes & M. A. Miles (eds.), *The trypanosomiasis*, CABI Publishing, Wallingford, UK.

54. SHERENI, W. 1990. Strategic and tactical developments in tsetse control in Zimbabwe (1981-1989). *Ins. Sc. Appl.* 11: 399-409.

55. SWALLOW, B. M. 1999. *Impacts of trypanosomiasis on African agriculture*. PAAT Technical and Scientific Series 2. FAO, Rome, Italy.

56. TAKKEN, W., M. A. OLADUNMADE, L. DENGWAT, H. U. FELDMANN, J. A. ONAH, S. O. TENABE & H. J. HAMANN. 1986. The eradication of *Glossina palpalis palpalis* (Robineau-Desvoidy) (Diptera: Glossinidae) using traps, insecticide-impregnated targets and the sterile insect technique in central Nigeria. *Bull. Entomol. Res.* 76: 275-286

57. THOMSON, J. W. & A. WILSON. 1992. The control of tsetse flies and trypanosomiasis by the application of deltamethrin to cattle. *Bull. Anim. Health Prod. Afr.* 40: 5-8.

58. UNITED NATIONS (UN). 2000a. *Millennium report of the Secretary-General of the United Nations*. 3 April 2000. New York, NY. USA.

59. UNITED NATIONS (UN). 2000b. *Implementation of the first United Nations decade for the eradication of poverty* (1997-2006). Report of the Secretary-General of the United Nations. 21 September 2001. New York, NY. USA

60. UNITED NATIONS (UN). 2001. *The role of the United Nations in support of the efforts of the African countries to achieve sustainable development*. Report of the Secretary General. High Level Segment, substantive session of 2001, 2-27 July 2001, Geneva, Switzerland. Economic and Social Council of the United Nations (ECOSOC) E/2001/CRP.3.

61. VALE, G. A., D. F. LOVEMORE, S. FLINT & G. F. COCKBILL. 1988. Odour-baited targets to control tsetse flies, *Glossina* spp. (Diptera: Glossinidae) in Zimbabwe. *Bull. Entomol. Res.* 78: 31-49.

62. VLOEDT VAN DER, A. M. V., D. A. T. BALDRY, H. POLITZAR, H. KULZER & D. CUISANCE. 1980. Experimental helicopter applications of decamethrin followed by release of sterile males for the control of riverine vectors of trypanosomiasis in Upper Volta. *Insect Sci. Applic.* 1: 105-112

63. VREYSEN, M. J. B. 2000. S*outhern Rift Valley Tsetse Eradication Programme: Analysis of he entomological base-line data collected between October 1998 and September 1999*. Report to the IAEA. IAEA, Vienna, Austria.

64. VREYSEN, M. J. B. 2001. Principles of area-wide integrated tsetse fly control using the sterile insect technique. *Med. Trop.* 61: 397-411.

65. VREYSEN, M. J. B. 2005. Monitoring sterile and wild insects in area-wide integrated pest management programmes. *In*: Dyck, V.A., J. Hendrichs & A. S. Robinson (eds.), *Sterile insect technique. Principles and practice in area-wide integrated pest management*. Springer, Dordrecht, The Netherlands. pp. 39-68.

66. VREYSEN M. J. B., J. GERARDO-ABAYA & J. P, CAYOL. 2007. Lessons from area-wide integrated pest management (AW-IPM) programmes with an SIT component: An FAO/IAEA perspective. *In:* Vreysen, M. J. B, A. S. Robinson & J. Hendrichs (eds.), *Area-wide control of insect pests - From research to field implementation*. Springer, Dordrecht, The Netherlands. (in press).

67. VREYSEN, M. J. B., A. MEBRATE, M. MENJETA, B. BANCHA, G. WOLDEYES, K. MUSIE, K. BEKELE & G. ABOSET. 1999. The distribution and relative abundance of tsetse flies in the Southern Rift Valley of Ethiopia: preliminary survey results. *In: 25th meeting of the International Scientific Council for Trypanosomiasis Research and Control*, Mombasa, Kenya, 27 September - 1 October, 1999, OAU/IBAR, 202-213.

68. VREYSEN, M. J. B., K. M. SALEH, M. Y. ALI, A. M. ABDULLAH, Z. R. ZHU, K. G. JUMA, V. A. DYCK, A. R. MSANGI, P. A. MKONYI, AND H. U. FELDMANN. 2000. *Glossina austeni* (Diptera: Glossinidae) eradicated on the island of Unguja, Zanzibar, using the sterile insect technique. *J. Econ. Entomol.* 93: 123–135.

69. WHO (WORLD HEALTH ORGANIZATION). 1998. *African trypanosomiasis; Control and Surveillance.* Report of a WHO expert committee, WHO technical report series no. 881. WHO, Geneva.

70. WILLIAMSON, D.L., D. A. DAME, D. B. GATES, P. E. COBB, B. BAKULI & P. V. WARNER. 1983. Integration of insect sterility and insecticides for control of *Glossina morsitans morsitans* (Diptera: Glossinidae) in Tanzania: V. The impact of sequential releases of sterilized tsetse flies. *Bull. Entomol. Res*. 73: 391-404.

71. WYSS, J. H. 2000. Screw-worm eradication in the Americas – overview. *In*. Tan, K.-H. (ed.), *Area-Wide Control of Fruit Flies and Other Insect Pests*. Proceedings International Conference on Area-Wide Control of Insect Pests, and the 5th International Symposium on fruit flies of economic importance, 28 May – 5 June 1998, Penang, Malaysia. Penerbit Universiti Sains Malaysia, Pulau Pinang, Malaysia. pp. 79-86.

Recibido: 17-I-2006
Aceptado: 1-VI-2006