Abstract

The tsetse and trypanosomiasis problem is characterized by many interdependencies involving agro-economical, social and environmental issues. Any intervention (or non-intervention) will have a wide range of immediate and longer-term implications.

In most African countries, demographic developments demand that agricultural systems become more productive. Increased productivity is difficult to implement because of the tsetse and the trypanosomiasis problem, which appears to have worsened over the past years: the number of sleeping sickness cases is exceeding even the level recorded during the epidemics of the 1920s. In several African countries, tsetse flies reinfest formerly reclaimed areas, invade previously uninfested agricultural areas, cause escalating problems in areas suffering from civil unrest and further decrease the area of land available for high-productivity agricultural systems. Controlled or substantially reduced vector populations can still be very efficient transmitters of trypanosomes. Some intervention measures have undesirable side-effects. Trypanosomes have developed resistance and cross-resistance to various trypanocides. The extensive use of insecticides on cattle for tsetse control appears to have the potential to interfere with the zootic stability/immunity of cattle to several tick-borne diseases, so long-term tsetse control may exacerbate other secondary problems. The environmentally acceptable methods for tsetse and trypanosomiasis management that are currently available all have specific limitations. In infested areas, only a combination of several methods in an integrated, phased and area-wide approach (Knipling, 1972; Chandler and Faust, 1998; Klassen, 2000) can effectively advance the establishment of viable agricultural systems that suit the needs of the rapidly growing human population.

The trypanosomiasis problem is not restricted to individual countries but is transnational and must be tackled on a regional, or at least a subregional, level. Although several donors currently favour integrated disease management through interventions in selected areas, an area-wide integrated pest management approach should be incorporated into such broader development concepts, and the option of creating tsetse fly-free zones should be pursued wherever this is feasible and sustainable. It is essential that a variety of options be retained, including the elimination of the tsetse and trypanosomiasis problem from large areas.

The potential for integrating several available intervention methods and for new supportive technologies has not been sufficiently explored. This is particularly the case for the sterile insect technique (SIT) which, unlike other conventional methods of tsetse control, has a unique efficiency pattern: efficiency increases as target pest population density decreases. A sequence of conventional methods, with SIT as a final component, would have maximum efficiency throughout an intervention campaign.

The recent eradication[1] of the tsetse fly in Zanzibar (Vreysen *et al.*, 2000) by means of aerial releases of large numbers of sterile males has received considerable attention. The major difference between the Zanzibar operations and previous tsetse SIT projects is aerial release capability, which allows for the systematic and area-wide application of this environmentally friendly intervention method, especially in inaccessible areas.

FAO and the International Atomic Energy Agency (IAEA) have

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[1]Although the term “eradication” means the extinction of a species from the earth, in this publication it is applied to localized complete removal of a population of the species, i.e. creation of a fly-free zone. Colonies of the “eradicated” insect population will be maintained, ensuring that various genetic information and molecular and other tools, which may be desired in the future, are preserved. The mass colonization of a pest species for SIT releases also implies that the “eradication” situation could be reversed in a very short time by intentionally releasing fertile adults. The World Health Organization (WHO, 2001) defines “eradication of disease” as a status, whereby *no further cases of a disease occur anywhere*, and *continued control measures are unnecessary*. “Elimination of disease” is defined as the *reduction of case transmission to a predetermined very low level* (e.g. one case per 10 000 or 1 million of the population). “Control of disease” is defined as *ongoing operation*s or programmes aimed at reducing the incidence and/or prevalence, or eliminating, such conditions.

launched an initiative to upgrade SIT to make it an economically attractive alternative for integration into area-wide subregional tsetse and trypanosomiasis intervention campaigns. This is a focused component of an overall initiative in livestock disease and wildlife management and agricultural development. Methods are under development for the release of at least 500 000 sterile males per week in the near future, which would enable operation in areas as extensive as 5 000 to 10 000 km^2 at a time. The initiative consists of three components: 1) research and development on tsetse rearing automation and more efficient aerial release systems, on tsetse attractants and on tsetse genetics; 2) an effort to increase awareness and determination among Africa's top decision-makers and more concerted, impact-oriented technical assistance support from the UN family and other major stakeholders, including declared milestones and verifiable implementation indicators; and 3) the identification of priority intervention areas along with the preparation, and eventual implementation, of feasibility demonstrations of the SIT package as a component of area-wide, integrated tsetse and trypanosomiasis management efforts. Substantial progress is being recorded on all three points, and one achievement relevant to point 2) deserves particular attention and represents a challenge for all the partners involved in tsetse/trypanosomiasis research and intervention: the African Heads of State and Government decision on tsetse eradication, AHG/Dec.156(XXXVI) (PAAT, 2000), passed at their 36th summit in Lomé, Togo. The summit "commends those African countries that have initiated the application of sterile insect technology (SIT) for their pioneering effort" and "urges Member States to act collectively to rise to the challenge of eliminating the problem through concerted efforts in mobilizing the necessary human, financial and material resources required to render Africa tsetse-free within the shortest time possible". As part of an integrated area-wide approach, SIT appears to be the most environmentally friendly component for implementing this decision. This publication addresses some of the challenges that remain and the major points of criticism raised in connection with SIT.

Contents

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Chapter 1

Background

Tsetse flies infest 36 countries and a total area of between 9 and 10 million km^2 in Africa. Throughout this area the disease transmitted by the tsetse fly, trypanosomiasis,[1] has a devastating effect on huge numbers of livestock. About 50 million cattle and tens of millions of small ruminants are at risk from trypanosomiasis. Direct losses in meat production and milk yield and the costs of programmes that attempt to control trypanosomiasis are estimated to amount to between US$600 million and $1.2 billion each year (FAO, 1994). According to the World Health Organization (WHO), more than 60 million people, mainly living in rural areas of sub-Saharan Africa, are at risk of human African trypanosomiasis (HAT), also called sleeping sickness. Some 45 000 new cases were reported in 1999, but this figure does not reflect the real epidemiological situation because surveillance is poor (covering only 5 to 7 percent of the people at risk). The estimated number of infected persons is between 300 000 and 500 000 (WHO, 2000). For an active surveillance programme to be effective, it would have to cover 70 percent of the people at risk which would cost some US$35 million per year, in addition to the annual US$38.5 million needed for drugs to treat 300 000 cases (FAO, 2000).

Unlike Asia, Europe and the Americas (where tsetse flies do not exist), crop farming and livestock production in sub-Saharan Africa are largely separated owing to the presence of tsetse flies. According to Harrison (1996) the "best potential for fodder production lies in the humid areas, 18 percent of the land area. But only 6 percent of Africa's livestock are

[1] Although "trypanosomosis" is the scientifically correct term for the disease (Kassai *et al.,* 1988; OIE, 2000), the term "trypanosomiasis" is accepted for use, particularly in English-speaking countries.

found here – scattered pockets of dwarf cattle, sheep and goats, resistant to trypanosomiasis. In this region, humans – chiefly women – are the main beasts of burden; the hoe stands in for the plough, and the head for the horse's back". Hursey and Slingenbergh (1995) confirm that, of 165 million cattle in sub-Saharan Africa, only 10 million are located in tsetse-infested areas, and the remainder are distributed at the periphery. The 464 million cattle in South America (which has a land mass that is only 58 percent as large as Africa's) are an indicator of the potential for African agriculture without tsetse. Tsetse and trypanosomiasis are the major factors preventing the establishment of sustainable agricultural systems in sub-Saharan Africa. Based on Govereh's (1999) work, Swallow (FAO, 2000) estimates that, if draught animals were available, a family that is currently dependent on manual labour alone could increase its income from agricultural work by 45 percent per unit of land and 143 percent per unit of labour. If the lost potential in livestock and crop production is included, trypanosomiasis is estimated to cost sub-Saharan Africa US$4 billion or more each year, equivalent to one-quarter of the area's total livestock produce (FAO, 1994). This is corroborated by Budd (1999) who estimates that, if it were possible to eradicate trypanosomiasis from Africa, the benefit to overall agricultural production would gradually rise to US$4.5 billion per year. In addition, the loss of human potential is virtually incalculable.

If this problem is not addressed vigorously, these losses will undoubtedly increase as the population expands further. The resultant poverty and political instability that will inevitably follow will also increase, thereby seriously curtailing opportunities for development. Trypanosomiasis is among the most devastating diseases in sub-Saharan Africa and is at the root of poverty, while the tsetse fly is considered to be one of the most serious pest problems in the world today.

Chapter 2

Past and present efforts to control tsetse and trypanosomiasis

Each of the available methods for tsetse and trypanosomiasis control or eradication has its own specific limitations. Some of the interventions conducted in the past, such as bush clearing (tsetse habitat destruction) or the elimination of wild animals (tsetse reservoir hosts), have been discarded for ecological and environmental reasons. Limitations are also imposed on the indiscriminate use of effective insecticides through aerial spraying. At present, the following less controversial interventions are available:

- parasite control through:
  - the use of trypanocidal drugs and, in some cases,
  - the promotion of trypanotolerant livestock;
- vector control or eradication through:
  - traps and insecticide-treated targets, in some cases baited with attractant odours,
  - insecticide-treated animals,and
  - the sterile insect technique (SIT).

Over the last two decades, the sequential aerosol technique (SAT) against tsetse fly populations (i.e. the aerial spraying of tsetse habitats using non-persistent insecticides) was under particular attack from environmentalists. Nevertheless, techniques similar to SAT may have a role as part of an integrated area-wide campaign: the committee of the Programme Against African Trypanosomiasis (PAAT) (which is coordinated by FAO, the International Atomic Energy Agency [IAEA], WHO and the Organization for African Unity's Interafrican Bureau for Animal Resources [OAU-IBAR]) notes the "relevance of the SAT technique for application to sleeping sickness epidemics" and recommends, "in recognition of the justification for area-wide pest management, … the consideration of SAT and SIT as techniques which both offer potential to make a significant contribution to the control and ultimate eradication of tsetse flies" (PAAT, 1998).

It has to be stressed that, although the strategies for using these options may vary considerably (depending on the specific objective, technical and logistical feasibilities, costs, etc.), in most circumstances, viable agricultural systems can be established effectively only when several methods are combined. Intervention methods must be applied to situations in which control or eradication is sustainable. This implies that the existing and possible future constraints of single methods (even when these are used in combination with others) should be carefully assessed and, if possible, eliminated. Some of the existing and potential constraints, main criticisms and relevant action needed are briefly discussed in the following sections

TRYPANOCIDAL DRUGS

The use of trypanocidal drugs is the most widely accepted means of controlling the disease. However, the drugs available are relatively expensive. In some African countries, sales of trypanocides account for more than half of the total sales of veterinary pharmaceuticals. In spite of this, the development of new trypanocides appears to be economically unattractive. Each diagnosis for animal trypanosomiasis costs about US$4 to $5, which African livestock owners cannot afford. As a result, more than 90 percent of the doses are applied without a reliable diagnosis (Bauer, in press). The widespread, unsupervised and underdosed use of the few compounds developed for use against the trypanosomes that cause disease has led to increasing resistance on the part of the parasite (Afewerk *et al.*, 2000), which retains its resistance after cyclical transmission by tsetse (Gray and Roberts, 1971). In spite of the increasing number of case reports on trypanocide resistance, Geerts and Holmes (FAO, 1998) highlight the lack of reliable data at the regional or national levels on the true prevalence and impact of drug resistance. They urge the development of measures to manage resistance to trypanocides, if possible, and the provision of guidelines to delay the development of resistance. It is alarming that fake drugs with little or no therapeutic effect account for an estimated market portion of up to 60 percent in developing countries (Holmes, 1997). This growing international threat to human and animal health demands the introduction of appropriate drug quality assurance procedures. According to Jordan (1986), the overall prospects for the use of trypanocidal drugs against African animal trypanosomiasis (AAT) are not bright because of widespread drug resistance and cross-resistance. Furthermore, he underlines that the situation is now worse than it was a few decades ago, and hopes are not high that any new effective trypanocide will be on the market in the foreseeable future.

TRYPANOTOLERANCE

When exposed to trypanosomiasis, trypanotolerant cattle breeds generally show slightly lower mortalities than are shown by trypanosusceptible breeds (up to 10 percent for trypanotolerant breeds compared with 10 to 20 percent for trypanosusceptible ones), and lower reductions in calving rate (1 to 12 percent compared with 11 to 20 percent) (FAO, 2000). Such trypanotolerant breeds are being promoted in several parts of Africa (FAO, 1987a, 1987b, 1988b). In some areas, particularly where zebu cattle are maintained, trypanotolerant cattle breeds have a reputation for inherently lower productivity and milk yield. Their suitability as draught animals is disputed, and the question repeatedly arises as to whether continuous, low parasite challenge or, possibly, treatments with trypanosome fragments are needed to maintain the desirable trait of trypanosome resistance; but, at least in areas under low tsetse and trypanosomiasis challenge, there appears to be insufficient evidence to support this practice. In areas that are densely infested with tsetse flies or when a lower level of trypanosomiasis challenge is combined with other stress factors, such as ploughing or malnutrition, trypanotolerant breeds of livestock will need the protection of trypanocidal drugs in order to be productive (Jordan, 1995). The selection of improved trypanotolerant breeds for use in livestock systems under low parasite challenge requires more efficient tools for exploiting resistance traits (d'Iteren *et al.*, 1999). When the genetic basis for trypanotolerance has been fully understood, it might become possible for this trait to be incorporated into other breeds of animals, thus creating transgenic cattle. Whether such a course of action would be widely acceptable remains to be seen.

USE OF INSECTICIDES

The use of special insecticide formulations applied to artificial attractive devices (insecticide-impregnated targets with or without available odour attractants) and cattle is an efficient and sufficiently specific method to suppress tsetse target populations in most situations (Challier and Laveissière, 1973; Vale, 1974, 1993; Küpper *et al.,* 1982; Brandl, 1988; SEMG, 1995; Bauer *et al.,* 1995; Bauer, *in press*). Success largely depends on the density and placement of the impregnated attractive devices in the fly habitat (Vale, 1998); the availability of attractants for the target tsetse species (Green, 1988, 1994; Torr, Hall and Smith, 1995, Torr *et al.*, 1997); the size of the control area; reinvasion pressure and the population dynamics of tsetse populations in adjacent areas (Van den Bosshe and Duchateau, 1998; Hargrove *et al.*, 2000; Hargrove, 2000; Bauer, in press); tsetse host preference (Weitz, 1963; Clausen *et al.*, 1998); and pastoralist practices, i.e. the time and location of grazing and peaks of tsetse activity. Projects that rely on these methods aim at community participation in order to promote self-sustainability after foreign assistance has been terminated. However, campaigns in East, West and Southern Africa showed that local communities' initial enthusiasm to participate in the tsetse control efforts and to place tsetse traps and insecticide-impregnated targets in relatively small areas is not sustained once institutional support ends (Jordan, 1995). Barrett and Okali (1999) conclude that community participation is not appropriate as an overall strategy for tsetse control, but may work in some cases, based on a better understanding of the roles and modes of interaction of partners at different levels.

Fortunately, observations (Baylis, Mbwabi and Stevenson, 1994) show that *Glossina pallidipes* populations in Kenya apparently do not exhibit a reduced feeding response to the presence of pour-on insecticide formulations on cattle, indicating that "behavioural" insecticide resistance has not yet developed. However, it is likely that one or more of the pyrethroid resistance mechanisms already known from several other species of Diptera will manifest themselves in tsetse (Georghiou *et al.*, 1993), in response to the increased selection engendered by wider adoption of deltamethrin-treated targets for tsetse control at the village level.

As with trypanocides, the widespread, unsupervised and insufficiently coordinated use of insecticides on targets or animals risks promoting the development of insecticide resistance. Therefore, a major responsibility of the international community involved in tsetse and trypanosomiasis management is to develop guidelines and to assist in the coordination and supervision of the appropriate use of insecticides for tsetse control through government services, non-governmental organizations (NGOs) and the private sector. Even when alternative methods are used, such as the application of SIT on a larger scale, integrated tsetse control or eradication campaigns will, in certain phases of project operations, continue to rely on the availability of effective insecticides for the initial suppression of populations (Cuisance *et al.* 1980; Van der Vloedt *et al.*, 1980).

PAST AND PRESENT EFFORTS

Travel reports from early explorers (see Ford, 1971) describe areas that are currently tsetse-infested as agricultural land with farms and cattle. The rinderpest pandemic at the beginning of the twentieth century wiped out huge numbers of wild animals and about 98 percent of the cattle from an area that extended from the Sudan to South Africa (Tedla, 1994). Before rinderpest arrived, the cattle on the plains kept tsetse in check by grazing the grass sward very close and preventing tree seedlings and shrubs from growing more than a few centimetres high (Pearce, 2000). According to Tedla (1994) the sudden, rinderpest-induced termination of vegetation control by grazing systems significantly altered the socio-economic balance of pastoral and agricultural communities; some wooded grassland became forests while open savannah reverted to scrub cover, enhancing the spread of the tsetse fly. As wildlife repopulated these habitats, an environment developed that was highly conducive to tsetse. The colonial powers decided to confine elephants, humanity's only rivals as an agent of vegetation change (Ford, 1971), to game reserves, thereby preventing the seasonal destruction of huge areas of bushland by migrating herds of elephants. In doing so, they unknowingly undermined the continuous creation of natural barriers against the advancement of tsetse.

Some 40 to 50 years ago, extensive tsetse control campaigns were under way in a number of African countries. These applied parasite and vector control operations on a large scale, involving some techniques that would no longer be acceptable today because of recent environmental concerns. The approach usually followed a strategy that would now be called area-wide, and several of these campaigns succeeded in eliminating tsetse from large areas of land, particularly at the edges of the tsetse belt (Dutoit, 1954; Speilberger, Na'Isa and Abdurrahim, 1977). However, knowledge about the complexity of the tsetse/trypanosomiasis problem, the level of subregional cooperation and the technologies available were insufficiently advanced to allow the expansion of successful campaigns across national boundaries and to cover all – including the less easily accessible – fly habitats adequately. Thus, tsetse (and trypanosomiasis) eradication and the disruption of cyclical trypanosome transmission could only be sustained in a few areas. In many other areas, the barrier technology that was then available (aerial and ground spraying) proved to be too labour-intensive and/or expensive to sustain the results achieved. Partially related to situations of civil unrest, tsetse eradication operations were discontinued and tsetse reinfested large areas of previously cleared habitat.

In subsequent years, donor interest in livestock projects and tsetse/trypanosomiasis control, which is largely a less visible rural problem, declined. The insufficient funding available to sustain area-wide implementation and supervision of tsetse and trypanosomiasis control methods, coupled with the necessity for cattle owners to pursue autonomous and uncoordinated control, led in many situations to the misuse of trypanocidal drugs and favoured the establishment of trypanocide resistance. Although the inadequate use of insecticides was also observed, the development of insecticide resistance among tsetse has, so far, not been reported. Fortunately, both the very high susceptibility of tsetse to pesticides and the reproductive biology of the pest do not favour a similarly quick selection for resistant insect strains as has been observed with other dipteran pests. Nevertheless, when planning and implementing tsetse control activities, it must be recognized that different insecticide application practices favour or disfavour the development of insecticide resistance in different ways.

In recent years, the failure of some of the early programmes, the diminishing funds available for large programmes and the rapid development of effective attractant traps and targets contributed to a shift in strategic thinking, away from eradication of the flies and the disease. Instead, a community-based integrated tsetse and disease management approach has been proposed for application in selected areas, where the "tsetse-livestock interface" prevents the establishment of sustainable agricultural systems.

However, in many of the areas where such community-based campaigns have been enthusiastically initiated and successful in reducing tsetse and disease risk, enthusiasm has waned, traps and screens have been neglected and flies and disease have returned (Jordan, 1995; Barrett and Okali, 1999). In this context, the re-establishment of a tsetse population from a relic core of flies that were not affected by the control operations appears even more risky than reinfestation from an uncontrolled area, because it may favour selection for insecticide resistance. Hargrove's (2000) theoretical studies of tsetse fly invasion of cleared areas confirm that reinfestation problems are most severe when the area cleared from tsetse is surrounded by untreated tsetse-infested country and is small in size (in the order of 100 km^2). Consequently, reinfestation problems are less severe when a strategy similar to the rolling-up approach of the New World screwworm eradication programme in Central America is adopted (Wyss, 2000). This favours larger tsetse eradication campaigns that start at the edge of the tsetse belt and advance the eradication front, leaving tsetse-free zones behind them.

With regard to environmentally acceptable tsetse and trypanosomiasis intervention methods, FAO and IAEA contend that the potential of some available methods has not been sufficiently exploited. This is particularly the case with SIT as a component of an area-wide integrated approach. Therefore, there is still the possibility to reverse the trend of mounting losses caused by expanding tsetse and trypanosomiasis.

FAO and IAEA anticipate that methods to upscale the mass rearing of tsetse flies and improve supportive techniques for use in SIT will continue to make good progress, and that SIT, when applied in combination with conventional efforts in a subregional, well-coordinated area-wide effort, can contribute to the creation of tsetse-free zones in large development areas. Existing knowledge and methods appear to be adequate for the integration of various proven methods, ranging from aerial spraying to SIT (Allsopp, 2001), in larger-scale and area-wide intervention campaigns. Through the systematic use of these technologies, it seems quite possible that progressively larger areas could be cleared of the vector and the disease, and that these pest-free zones could be maintained at relatively small cost. Indeed, although such zones would initially be confined by (temporary) human-made barriers, they could eventually be expanded to reach naturally occurring barriers.

African Heads of State and Government, at their 36th Ordinary Summit in Lomé, Togo in July 2000, passed a decision (AHG/Dec.156[XXXVI]) to eradicate tsetse flies from Africa (OAU, 2000; PAAT, 2000) and requested OAU's Secretary-General to undertake all necessary consultations and seek support and cooperation from all possible partners in the implementation of the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC). The eradication of tsetse from the entire continent goes beyond the discussion of this publication, which instead aims at outlining a concept for integrating SIT into area-wide campaigns in order to create, and subsequently expand, tsetse fly-free zones in identified priority areas for intervention and subsequent development.

Chapter 3

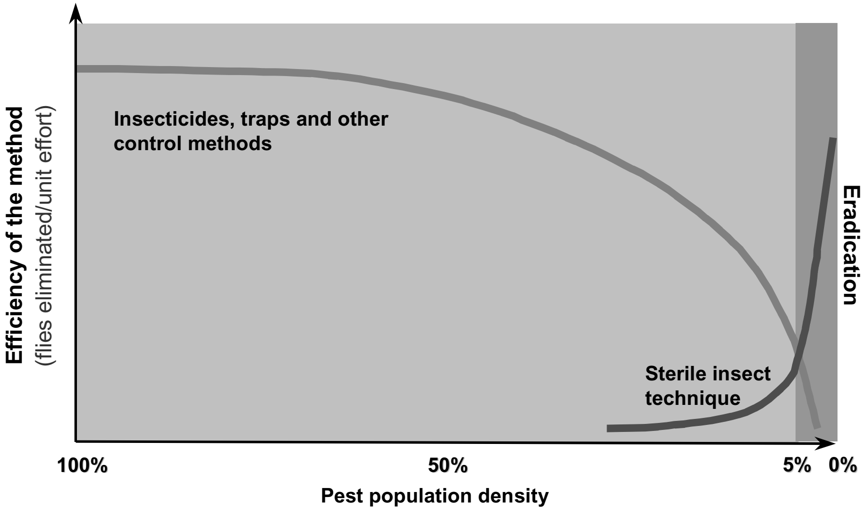
The sterile insect technique

The sterile insect technique (SIT) involves sustained, systematic releases of sterile insects among the indigenous target population. When female flies are mated by sterile male flies, the females become infertile for the remainder of their life spans. The insects to be released are propagated at special large-scale rearing facilities. Males are sterilized by radiation at the appropriate stage and then taken to the selected area and released. Distribution of the sterile insects can be optimized by aerial release. By continually releasing sterile males in quantities and over a time span that is sufficient to cover several generations of the target population, its reproductive capacity and, hence, the fertile population are progressively reduced. Eventually, so few fertile insects remain that fertile matings do not occur and the population is eliminated.

For maximum effectiveness, the sterile males released must outnumber the fertile, native male flies by a considerable margin. In order to reduce populations when conditions are highly favourable for fly reproduction, the ratio of released sterile males to native males should be at least 2 to 1 (Knipling, 1955) and may, in certain circumstances, have to be as high 15 to 1. It therefore follows that SIT is most cost-effective when the target population is low. On the other hand, insecticide applications cost the same, regardless of the insect population density and are, therefore, most cost-effective when the target population density is high. This suggests that the phased and complementary use of both "conventional" methods and SIT would result in maximum efficiency throughout the phase of intervention (Figure 1). For some populations, and for species of insect pests that have strong seasonal fluctuations, SIT releases may be initiated and the number of sterile males released cause efficient "overflooding" ratios even when native populations have not

FIGURE 1

Optimizing the efficiency of an insect pest intervention campaign by using conventional control and SIT in an integrated, phased approach



been suppressed by conventional means prior to the SIT release. Contrary to the conventional integrated pest management (IPM) concept, which suggests interventions should only be made after a pest population has exceeded the economic threshold level, SIT is initiated when the target pest population reaches its seasonal minimum, for example, at the end of the winter, long before it starts increasing again.

Chapter 4

Feasibility considerations

TECHNICAL FEASIBILITY OF SIT FOR INSECT ERADICATION

SIT for insect eradication

The technical feasibility of eradication using SIT has been documented (Linquist *et al*., 1990; Hendrichs, 2000). The successful eradications of the New World screwworm fly from North and Central America (Wyss, 2000), the Mediterranean fruit fly from areas in North, Central (including Mexico, Hendrichs *et al*., 1983) and South America (including all of Chile, SAG, 1995), the melon fly from Okinawa Islands (Kuba *et al,* 1996) and the Queensland fruit fly from Western Australia (Fisher, 1996) are all well known. For many years it was argued that screwworm eradication using SIT was technically and logistically impossible, but major successes in eradicating the New World screwworm from all of North and most of Central America, as well as from North Africa, have shown otherwise. The same arguments that were once used against the feasibility, justifiability and sustainability of screwworm eradication are being used today with regard to tsetse eradication. Krafsur (1998) summarizes the controversial history of SIT in screwworm or fruit fly interventions. A comparison of screwworm and tsetse SIT development (Table 1) shows that the progression of these two applications, from laboratory development and field tests to general acceptance and use in major eradication programmes, is virtually identical.

The applicability of SIT to the tsetse fly

Adequate response to the tsetse and trypanosomiasis challenge requires a long-term strategy and a dynamic and flexible approach that includes several options for application with optimal timing, as described in the previous chapter. This also implies that, as a principle or policy, any vector control programme should be designed to include the option of

TABLE 1

Development of SIT for the New World screwworm (NWS) fly...

New World screwworm
1936 Laboratory techniques to culture screwworm, *C. hominivorax,* on ground meat developed by Dr Bushland.
1937 Chemicals used to induce sterility followed by X-rays and, later, gamma rays from cobalt 60.
1953 First field trial on Sanibel Island (36 km^2) off the coast of Florida, the United States. 80% sterility is achieved, but eradication fails owing to migration from the mainland.
1954 Field test on Curaçao (440 km^2), 64 km off the Venezuelan coast. 7 weeks after first releases of 150 flies/km^2/week no more fertile egg masses can be found on sentinel animals. Eradication is concluded after 5 months of weekly releases.
1957 Florida livestock owners persuade United States Congress to provide funds for a control programme.
1958 Eradication campaign starts in southern United States. New large rearing facility at Sebring, Florida, produces 50-75 million sterile flies/week. Last endemic case reported in June 1959.
1962 Southwest United States, eradication programme initiated for Texas (1 million cases treated prior to 1962), Arizona, New Mexico and California.
1965 Texas and New Mexico declared free of endemic infestation in the southwest United States.
1966 United States Department of Agriculture (USDA) declares the entire southwest United States free of infestation after cooperative eradication programmes in Arizona and California, thereby freeing the entire United States from screwworm.
1991 The Mexico-United States Screwworm Commission declares eradication of screwworm from the entire Mexican territory.
1992 Following the discovery of the New World screwworm in the Libyan Arab Jamahiriya in 1988, eradication is declared in North Africa after successful conclusion of an international emergency SIT campaign.
1994 Screwworm eradicated from Belize and Guatemala.
1995 FAO prepares a document on the eradication of screwworm from Jamaica, but funding cannot be secured.
1996 Screwworm eradicated from Honduras and El Salvador.
1997: IAEA complements FAO's planning activities for Jamaica and supports various preparatory activities.
1998-1999 Screwworm eradicated from Nicaragua.
1998 Jamaica, IAEA and other partners agree on project for eradicating screwworm from Jamaica.
1999 Start of sterile male releases in Jamaica.
1999-2001 Screwworm eradication planned for Costa Rica and Panama.
2001 Screwworm eradication planned for Jamaica.

... and the tsetse fly

Tsetse

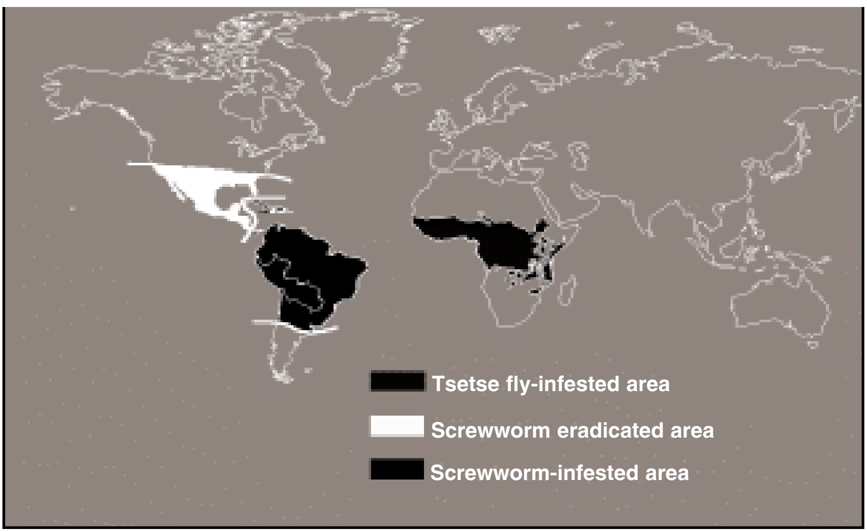
1966
Lake Kariba, Zimbabwe, field-collected *G. m. morsitans* adults treated with chemosterilants and released. Population eradicated in 26 months. In a later experiment, sterile flies are released as pupae and 95% induced sterility is reached in 10 months (experiment discontinued because of civil unrest).
1976
Tanga, United Republic of Tanzania, following two aerial applications of endosulfan, late-stage *G. m. morsitans* pupae from a goat-fed colony are radiation-sterilized (137Cs gamma rays) and released into a 195 km^2 control area. Target population reduced by 81%. 1 km bush-free barrier zone is insufficient to prevent reinfestation.
1981
Programme covering 3 500 km^2 (with 500-600 linear km of riverine forest) initiated in Burkina Faso. For the first time: i) insecticide-impregnated targets for tsetse population suppression are used; ii) simultaneous eradication of three species is attempted; and iii) g-ray-sterilized blood is used to feed tsetse at the rearing facility. Insecticide-impregnated targets reduce flies by 94%. Complete eradication achieved with SIT within 4 months, but the area becomes reinfested.
1979-1987
BICOT project in Vom, Nigeria, mass rears *G. palpalis palpalis* using guinea pigs, fresh bovine and freeze-dried porcine blood. Colony contains 180 000 females; target area is 1 500 km^2 (with 450 km of linear riverine forest); release ratio of 10:1 reached; and eradication achieved in 8-12 months (by mid-1987). For the first time, sterile virgin females are released and recaptured to confirm eradication. Owing to lack of financial support to extend the eradication area and maintain barriers, reinvasion occurs.
1993
Following substantial reduction of *G. austeni* population through pour-on formulations of insecticides by the Zanzibar Government and FAO/United Nations Development Programme (UNDP) on Unguja island, IAEA board approves a technical cooperation project aimed at tsetse eradication on Unguja (1 600 km^2). Most sterilized males provided by the Tanga mass rearing facility (FAO/IAEA laboratory serves as back-up).
1994-1997
In 1994 aerial releases are tested over Zanzibar. Mass releases start in May 1995 over the southern part of the island and, in mid-1996, over all Unguja. Population of colony females at the Tanga fly factory reaches almost 1 million and, in 1996, an average of more than 70 000 sterile males/week are released. Last fertile female captured in February 1996, last wild fly in September 1996. Last case of nagana in cattle detected in August 1997. Operational phase of the eradication project completed in late 1997.
1997
Ethiopian Government approves 10-year multimillion US$ project on tsetse eradication in 25 000 km^2 of the southern Rift Valley. Based on a phased, conditional planning approach, IAEA and collaborators initiate a comprehensive baseline data assessment and provide preparatory support in anticipation of sterile male production and releases.
2001
Test releases scheduled in Ethiopia

tsetse eradication, provided that this is technically feasible, economically justifiable and sustainable. In many cases, conventional techniques are highly effective in reducing fly populations, are sufficiently simple to be applied by farmers at the village level and are, therefore, promoted by many groups for continuous tsetse control in defined agricultural areas and involving community participation. These "low-tech" methods are often significant adjuncts to achieving relatively low native fly densities, but are not usually applied for tsetse eradication over extensive areas. However, under favourable conditions, this might be possible, provided that certain technical constraints are removed and several available tools are properly integrated with the principles of the area-wide concept.

Situations in which conventional technologies have resulted in dramatic reductions in tsetse populations are very favourable to the introduction of SIT, with its unique attribute of increasing efficiency as target population density decreases. In many situations, after the initial suppression of fly populations by conventional techniques, SIT's applicability in even very inaccessible areas and its proven capability to

FIGURE 2

Comparison of tsetse-infested and screwworm eradication areas



eradicate at high levels of target-specificity could make it the key missing ingredient in the current mix of techniques to combat the tsetse fly. However, before SIT can efficiently support larger, subregional tsetse and trypanosomiasis intervention programmes, several issues need to be addressed (see Chapter 5)

The map shown in Figure 2 indicates the area from which the screwworm fly has been eradicated in the Western hemisphere using SIT in an integrated area-wide approach. The tsetse fly-infested area in sub-Saharan Africa is of a similar size. The fact that the trypanosomiasis problem is sustained by several tsetse species, which are often found in fragmented populations (Figures 4, 5 and 6, p. 27), should be viewed as an advantage for expanding phased eradication operations, at least when compared with the screwworm situation. Using a combination of conventional techniques and SIT, *Glossina palpalis gambiensis*, *G. tachinoides* and *G. morsitans submorsitans* were eradicated from 3 500 km^2 in southern Burkina Faso (Cuisance *et al.*, 1986) and *G. p. palpalis* from 1 500 km^2 in central Nigeria (Oladunmade *et al.*, 1990). According to FAO (1988a), "it was also demonstrated that complete sterility could be induced in the wild population within only five months when the ratio of sterile to productive wild males was 9:1 or greater." However, these demonstrations of the technical feasibility of tsetse SIT in West Africa – which included the development of methods for future SIT campaigns such as the first experimental aerial releases (Politzar, Merot and Brandl, 1984) – were not part of a longer-term, strategic approach, were not based on the area-wide concept and did not give sufficient consideration to the sustainability aspects of project operations or of results achieved. This was different in the case of Zanzibar, where *G. austeni* was eradicated using SIT in an integrated area-wide approach (Vreysen *et al.*, 2000). In 1998 and 1999, the two years following the completion of tsetse eradication operations, more than 3 000 animals, randomly selected from all areas of Unguja Island of Zanzibar (United Republic of Tanzania), were bled. All were found negative for trypanosomes by the micro-haematocrit centrifuge technique, as they had been in all previous bleedings since September 1997 (Saleh *et al.,* in press*)*. In addition, fluctuations in the apparent density of the island's stable fly population were monitored. In spite of high concentrations of *Stomoxys niger* in some areas, it was found that the transmission of trypanosomes could not be sustained in the absence of tsetse flies. In collaboration with other partners, the Zanzibar authorities started to introduce genetically upgraded cross-breeds for improved meat and milk production, and people started to experience the benefits of improved livestock systems only one year after the tsetse operations had been completed (Kassim Juman, pers. comm.). An effort to generate a basis and, eventually, to quantify the benefits and development opportunities that result from or are related to tsetse eradication and elimination of the trypanosomiasis problem from Zanzibar was undertaken by Tambi, Maina and Mdoe (1999).

The fundamental biology of the tsetse fly is such that SIT may be even better suited to the eradication of this pest than it is to that of the screwworm fly, which has been the most successful large-scale application of SIT to date. The relevant factors are described in the following paragraphs.

Mass rearing. The mass rearing of tsetse flies has some important advantages over that of screwworm flies, fruit flies or moths. Table 2 compares tsetse and screwworm rearing. The screwworm requires special resources and rearing conditions at all stages of its development (i.e. egg, larval, pupal and adult), as does the medfly when subject to mass rearing. In the case of tsetse fly, only the pupal and adult stages have to be considered, because the egg and larval stages remain within the pregnant female fly.

Another factor is that, in nature, the larvae (or "worms") of the screwworm fly grow within living mammalian flesh. Therefore, for mass rearing purposes, a very complex larval medium that closely simulates the consistency and temperature of living tissue had to be developed and deployed on a very large scale. Medfly eggs need to be bubbled in special water baths, while the larvae require a special diet of defined nutrients,

TABLE 2

Comparison of mass rearing requirements for screwworm flies and tsetse flies

	Screwworm		Tsetse	
	Conditions	Resources	Conditions	Resources
Egg stage	39°C 70% RH 8-12 hours	Egging boards containing ground horse meat are used for egg deposition and transfer to gelled diet.		
Larval stage	1. 39°C 70% RH I day on diet 2. 37.8°C 70% RH I day on diet 3. 35°C 70% RH 4-5 days on diet	Living mammal flesh is simulated by a complex mixture of dried bovine blood, milk substitute, dried egg, formaldehyde, gelling agent and water.		
Pupal stage	Larvae in sawdust 1. 26.7°C 50% RH 1 day Separation from sawdust 2. 26.5°C 50% RH 5.5 days		23.5°C 80% RH 26.5°C 80% RH	For self-stocking of flies into production cages and self-separation of males for releases, pupae are incubated at increased temperature starting on day 32 post-larviposition.
Adult stage	24.6°C 50% RH	Flies feed on the wounds of animals as a protein source and on flowers as a source of carbohydrate and water. In the laboratory these three resources are provided in the form of honey, water and a protein source.	23.5°C 80% RH	Flies feed on blood of select host animals. For laboratory feeding, clean defibrinated blood, decontaminated by gamma radiation, is offered through a silicone membrane.

preservatives and texture. In medfly mass production, unless all the ingredients are subjected to a series of quality control screenings they will eventually cause major problems. At the adult stage, screwworm flies normally feed on the liquids in animal wounds to obtain their protein requirements, and on nectar from flowers for carbohydrates and water. The diet provided to an adult screwworm colony must take into account all these requirements.

The larvae of the tsetse fly do not have to be fed because they develop within the female fly. Adult tsetse flies do not require water or carbohydrates, only quality blood. Originally, living animals served as hosts to provide tsetse flies with a source of blood (Nash, Jordan and Boyle, 1968; Van der Vloedt, 1982; Williamson *et al.*, 1983a). This was not practical and was criticized by animal welfare groups. Since the development of a membrane feeding system (Bauer and Wetzel, 1976; Feldman, 1994b), which flies accept as host skin and through which they ingest the blood, living animals are no longer required as hosts.

Unlike the ingredients of the screwworm and medfly diet, many of which have to be imported using hard currency, animal blood for tsetse rearing can be collected at a local abattoir and then treated with gamma radiation to eliminate or reduce drastically any microbial contamination. Once tsetse mass rearing has reached the same scale of industrial production as was achieved for screwworm, local commercial sources in Africa will sell the required quantities of sterilized blood. In the meantime, much of this product is largely lost at slaughterhouses without benefiting local economies.

More effective eradication in the field. Another important biological factor is the low reproductive rate of the tsetse fly. In spite of a relatively long adult lifespan, this characteristic slows the rate of colony increase to mass rearing status and makes it necessary to maintain large stock colonies of flies for potential customers. However, the low reproductive rate also represents a tremendous advantage during field eradication programmes.

Once a wild population of tsetse flies has been suppressed by conventional methods and is subjected to continuous overflooding with sterile flies, it has less possibility to recover than a screwworm (and much less than a fruit fly) population has. These species are so-called “r”-selected individuals, and each fertile female (in the case of fruit flies) can lay some 700 to 800 eggs in a short period. This means that, even if only a few fertile wild females survive, undetected localized outbreaks can occur, thereby undermining large-scale eradication efforts. With tsetse flies, on the other hand, any fertile female that survives can only produce one offspring every nine to ten days, and the generation period is nearly two months. Even though undetectable relic populations can make tsetse populations recover fully within three to five years (Hargrove, 2000), the long generation period also indicates that temporary upsets in sterile fly quality, quantity or distribution have less of a negative impact on the outcome of an eradication campaign, and can therefore be more rapidly overcome with corrective measures in tsetse fly than in the other species.

There are also significant advantages in favour of tsetse SIT in terms of sterile fly release densities. For example, in Zanzibar the number of sterile males released ranged between 25 and 400/km^2, depending on how suitable the release area was as tsetse habitat. Sterile tsetse fly males were released at an average rate of between 55 and 100/km^2/week. Sterile screwworm flies were released in densities of between 1 200 and 1 500/km^2, and the number of sterile medflies released in eradication programmes ranged between 100 000 and 400 000/km^2.

Lower risk of tsetse reinfestation. Questions are often raised regarding the potential for reinvasion of areas from which a pest has been eradicated using SIT. In fact, the consolidation of areas that are already pest-free is the most challenging part of any control or eradication programme. A prerequisite for assessing the risk of tsetse reinfestation is a better understanding of fly movement. Initial models that assumed random fly movement (Rogers, 1977) facilitated a better interpretation of data from experiments or intervention projects, which are usually based on biased sampling techniques of insufficiently known efficiency. Subsequent publications on fly population dynamics and fly movement (Hargrove, 1981; Rogers, 1990; Williams, Dransfield and Brightwell, 1992) emphasized that the nature of tsetse dispersal is more complex and that fly release interventions need to reflect such parameters as seasonally fluctuating vegetation types, physiological conditions and factors involved in the regulation of fly population density. Yu *et al.* (1996) calculated the straight-line distance travelled in the life span of a tsetse fly to be < 1.71 km from its birth place, and estimated the spread distance for tsetse populations to be 18.7 km over a ten-year period. Some filed data (Cuisance *et al.*, 1981) and literature reviews (Rogers, 1977;

Hargrove, 2000) contradict this model and suggest that, although most tsetse cover only short distances at a time, a few individuals can move as far as 21 km along riverine forests within a relatively short period. From various literature sources, Hargrove (2000) has compiled a list of annual advancements of reinvasion fronts which range from 3 to 20 km. In general, tsetse species of the Fusca group tend to disperse more slowly than species of the Morsitans group (Dransfield *et al.*, 1991). Tsetse species of the Palpalis group tend to move even further and faster along riverine forests (e.g. *Glossina tachinoides* and *G. palpalis*) and lake shores (e.g. *G. fuscipes*) than is the case with the Morsitans group. Even assuming that various factors favour a unidirectional migration of flies into a free(d) area, the inability of tsetse flies to disperse at uniform speeds and levels of activity from one area to another, as other major insect pests can, remains an important biological characteristic and is a tremendous advantage in maintaining quarantine once an area is free of tsetse. In the case of screwworms, individual adults can disperse up to 290 km from the release point (Hightower, Adams and Alley, 1965), and the initial barrier zone maintained by the joint United States and Mexico screwworm eradication programme was set at 480 to 800 km (Jones, Scott and Cortinas, 1999). Iwahashi (1972) describes the "non-stop" movement of oriental fruit flies between island groups that are 27 to 50 km apart, while Kawai, Iwahashi and Ito (1978) report that melon flies can fly 30 to 50 km over the sea.

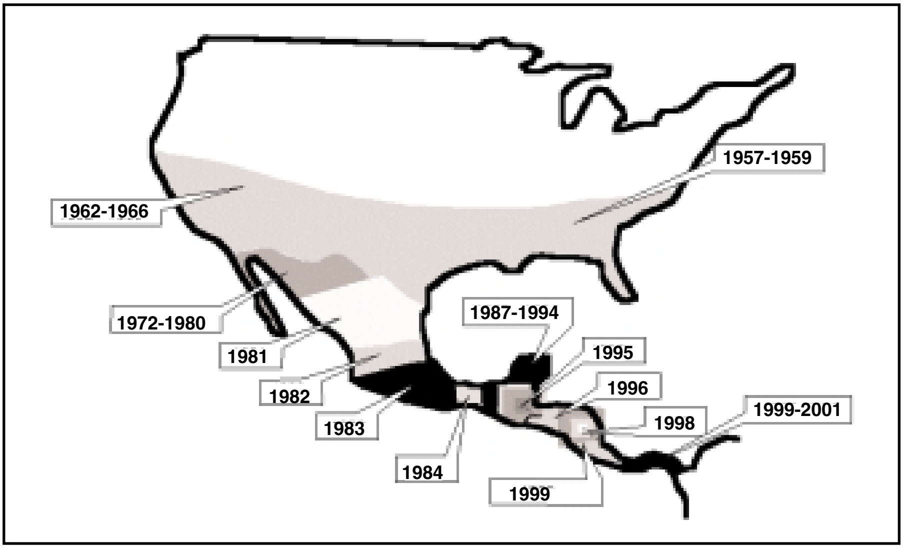
Any screwworm-infected host animal carries the larvae (worms) of the fly in wounds. The movement of infected cattle into a fly-free area automatically results in reinfestation. This was probably the means by which screwworm was introduced into North Africa from South America. In the case of fruit flies, any person carrying a worm-ridden fruit can reintroduce the pest into a fly-free area. Medfly outbreaks of this nature occur frequently in California, Florida and elsewhere. In the case of tsetse fly, the larvae develop within the female fly and not on or within animals or fruit. Therefore, animals or humans carrying fruit or other agricultural products cannot transport the immature stages of tsetse from one location to another. Only the passive transfer of adults via vehicles or, occasionally, animals (e.g. transhumant cattle) needs to be prevented.

A clear example of the limited invasion capacity of tsetse flies is seen on the two major islands of Zanzibar in the United Republic of Tanzania – Unguja and Pemba. Zanzibar has been a trading centre for the East African region for at least 500 years. Cattle from the mainland, where four economically important tsetse fly species are known to exist along the coastline, have been imported regularly to both islands for approximately the same amount of time. Unguja, however, was infested with only one species of tsetse fly, *Glossina austeni*, and there are no tsetse flies at all on Pemba, in spite of an environment similar to that of Unguja. Thus, even though there is frequent movement of people and animals across the 35 km that separate the islands of Zanzibar from the mainland, infestations of tsetse species from the mainland to the islands have not occurred.

Although the passive transport of individual adults on cars, etc. may occur, the tsetse fly mainly disperses and migrates through the flight capacity of individual flies. The minimum number of flies needed to establish a tsetse population in a fly-free area is not known. In any case, when compared with screwworm or fruit fly adults, tsetse's capacity for self-dispersal and establishment is quite limited. This is owing to the special proline-alanine-based metabolism of tsetse, which requires flies to rest between flights of relatively short duration. The movement of flies following wild host animals is thus limited to a maximum of a few hundred metres. Evidence of the tsetse fly in fossils and various mineral deposits shows that the natural isolation of the Zanzibar islands from infestation by mainland species has held for thousands of years. The origin of the single species that was present on Unguja may date back to the Pleistocene era, when the island was connected to the mainland by a sandbank.

The limited flight range of the tsetse fly and its avoidance of flight over expanses of water and, for many species, cleared land means that reinfestation can be prevented when barriers are sufficiently wide. This has been accomplished even in difficult situations. When insecticide-impregnated target barriers are used, Hargrove (1993) estimates the

FIGURE 3
Progressive shift of New World screwworm eradication zones using SIT in North and Central America



required depth of a barrier zone to be eight times the target placement distance (which is 500 m for *Glossina pallidipes*). Muzari's (1999) field experiments confirm that a 7- to 9-km wide band of odour-bated, deltamethrin-impregnated targets, placed at a density of four per square kilometre, represents an effective barrier to prevent the reinvasion of *G. pallidipes* in Zimbabwe. Integrated barriers using multiple control techniques, possibly including the release of sterile males, may be expected to result in higher efficiency than barriers that rely on one method only.

In spite of the greater difficulties in maintaining fly-free areas resulting from the pest's biology, the eradication of screwworm from North America proceeded successfully through a continuous series of broad eradication zones or belts that were rolled back as eradication proceeded. Each eradication phase in a new zone was preceded by suppression in large areas and followed by intensive monitoring for verification (Figure 3). The erection of effective (temporary) barrier zones is also feasible for

tsetse, but the management of artificial barrier systems to prevent the reinfestation of eradication areas needs further attention. The availability of new molecular tools for assessing tsetse population genetics (Krafsur and Griffiths, 1997; Krafsur *et al.*, 1997, 2000) and the gene flow between neighbouring tsetse populations, together with the use of information based on Geographical Information Systems (GIS), will further facilitate appropriate strategic decisions on the location of artificial barrier systems in the future.
The logistical challenges of a tsetse SIT operation are considerable but manageable and, as indicated in the following paragraphs, there are several situations in which an SIT component as part of an integrated area-wide campaign appears feasible and justifiable.

Opportunities for integrating tsetse SIT. Irrespective of the method used, any tsetse/trypanosomiasis intervention should aim at the sustainable alleviation or, if possible, the removal of a major tsetse/trypanosomiasis threat to existing or developing agricultural systems in Africa. The application of the area-wide concept would increase the efficiency of conventional control, limit undesirable environmental side-effects and limit the potential for the development of resistance to trypanocides and insecticides. The tsetse SIT component should be particularly considered under the following circumstances:

- The tsetse target population is located at the periphery of the tsetse belt, permitting a phased expansion of the eradication area.
- The target population is isolated in ecological islands, as confirmed by population genetic studies.
- There is evidence for tsetse and trypanosomiasis advancing into new, previously uninfested agricultural areas.
- Demographic development demands the introduction of highly productive livestock systems, for which substantial tsetse/trypanosomiasis control is a prerequisite and eradication of the problem is advised.
- Recurrent expenditures for continuous tsetse/trypanosomiasis control are not acceptable.

- The risk of civil unrest in the subregion poses a threat to the continuity of conventional tsetse/trypanosomiasis control activities.
- Tsetse-infested wildlife reserves and agricultural areas are in close proximity and constitute a threat to each other.
- Tsetse-infested areas of difficult topography are (temporarily) out of reach, and there is evidence that aerial releases of sterile tsetse are advantageous.
- There is environmentally detrimental, uneven distribution of cattle and signs of overgrazing adjacent to tsetse-infested areas with very low livestock density.
- There is a risk of reinfestation, but the anticipated phase of eradication will last sufficiently long to recover the investments made and justify subsequent renewed eradication efforts ("serial eradication", see the section on Economic feasibility on p. 34).

Considering the distribution and population dynamics of some tsetse populations, it is obvious that there are several island- or peninsula-like situations that are suitable for initial pilot interventions. The (incomplete) list of initial areas where tsetse SIT could play a role as part of an integrated area-wide campaign includes:

- Ethiopian valley systems (*Glossina pallidipes, G. fuscipes fuscipes, G. tachinoides*; Figures 4 and 5);
- islands such as Zanzibar (on Unguja Island, eradication of the only species, *G. austeni*, was completed in 1997) and Mafia (*G. brevipalpis*);
- peri-urban riverine systems in West Africa, for example the Bamako region in Mali (*G. palpalis gambiensis*), with an anticipated extension of the tsetse fly-free zone into the cotton belt of West Africa;
- the *G. f. fuscipes* belt around most of Lake Victoria (Figure 5);
- the Okavango delta in Botswana (*G. morsitans centralis*; Figure 6);
- northwestern areas of the United Republic of Tanzania and southwestern areas of Kenya (*G. swynnertoni* and *G. pallidipes;* Figure 4);
- the border region of South Africa and Mozambique (*G. austeni* and *G. brevipalpis*).

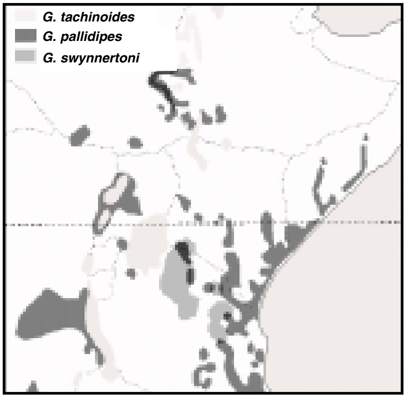


FIGURE 4

Approximate distribution of *Glossina swynnertoni*, *G. tachinoides* and *G. pallidipes* in East Africa

Source: after ORSTOM/CIRAD, 1998.

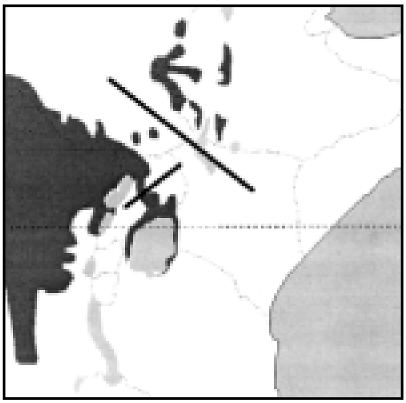


FIGURE 5

Approximate distribution of *Glossina fuscipes fuscipes* in East Africa

Source: after ORSTOM/CIRAD, 1998.

FIGURE 6

Approximate distribution of *Glossina morsitans centralis* in Southern Africa

Source: after ORSTOM/CIRAD, 1998.

Detailed technical and economic feasibility assessments should be conducted before embarking on major intervention campaigns, with or without SIT. There are sites for which the area-wide concept and an SIT component for tsetse/trypanosomiasis eradication deserve serious and thorough consideration.

ENVIRONMENTAL ISSUES RELEVANT TO TSETSE SIT AND CONCERNS REGARDING TSETSE ERADICATION

The following three main environmental concerns are repeatedly raised in relation to tsetse/trypanosomiasis eradication from affected countries in sub-Saharan Africa:

- Tsetse flies are important components of the African ecosystem, and the elimination of tsetse would upset the ecological balance of some areas and lead to a reduction in biodiversity.
- The presence of tsetse flies protects national parks.
- Tsetse eradication would result in uncontrolled agricultural expansion, overgrazing and erosion.

Biodiversity

An environmental survey of the effect of eradicating the tsetse fly from Zanzibar was conducted by Müller and Nagel (1994). In their report, they state: "From the environmental point of view, SIT is the safest technique of tsetse control or eradication. Released males will have an impact only on the tsetse fly population without any interference with non-target organisms. It is the only absolutely specific technique available."

Nagel (1991, 1994) states that no predator feeds exclusively, or even predominantly, on tsetse flies in such a way that the presence of the flies is indispensable for the existence of any other species. There is also no evidence of *Glossina* spp. being "key species" in their ecosystems, nor of their disappearance causing the destruction of those ecosystems as a result of the loss of the tsetse's original identity and functionality (Nagel, 1988). Because of their low reproductive capacity (a tsetse female deposits a maximum of only one offspring every nine days and, on average, only three throughout its life), tsetse's natural population density is extremely low, particularly compared with that of other blood-sucking insects. The European Union's (EU) Scientific Environmental Monitoring Group (SEMG, 1995) also concludes that there is no definite evidence that tsetse flies are key elements in the ecosystem.

Furthermore, unless the tsetse fly is eradicated, insecticides and trypanocidal drugs must be used continuously in an effort to limit the effects of trypanosomiasis. Thus, in addition to the direct benefits of eradication, the use of SIT also reduces any adverse effects on the environment and food safety resulting from current conventional control measures (for example, the reduced use of chemicals leads to reductions in the potential residues of drugs and insecticides found in meat, milk and dung).

Glossina pallidipes was eradicated between 1946 and 1952 from large areas of South Africa (Dutoit, 1954). The Kruger National Park has been free of tsetse since the rinderpest pandemic at the beginning of the twentieth century. There is no indication that the absence of tsetse has resulted in a decrease in biodiversity, or that it has affected the ecological balance.

Tsetse, particularly riverine species, frequently expand their habitats after agricultural activities have generated appropriate environmental conditions and provided suitable hosts. In the peri-urban agricultural system of Bamako in Mali, for example, *Glossina palpalis gambiensis*, a riverine species of tsetse that previously lived mainly on reptiles, is moving into irrigation schemes, establishing peri-domestic behaviour and changing host preference to humans and livestock (Bauer, 1994). The expansion of tsetse into, and its threatening of, newly established agricultural systems and other ecosystems have also been reported (Leak and Mulatu, 1993; Kassaye Hadgu *et al*., 1995).

The World Bank (World Bank Group, 1998) predicts that there will be a general spread of disease vectors resulting from higher precipitation and warmer winters in some areas. The expansion of tsetse, and the new epidemiological risks associated with such detrimental developments, would require area-wide corrective and preventive tsetse and trypanosomiasis intervention measures.

Game reserves

When Europeans arrived in Africa at the beginning of the nineteenth century, they perceived “this bushy, tsetse-ridden landscape, newly emptied [by the rinderpest pandemic] of people and cattle and teeming with wildlife instead”, as “their archetype of ‘unspoilt’ Africa” (Pearce, 2000). Assuming that what they were looking at was the pristine environment of the African savannah, conservationists created Africa’s great national parks and, initially unaware of the ecological balance that had existed for thousands of years among cattle, people and wildlife in the dynamic savannah ecosystems, these “colonial ecologists” (Pearce, 2000) or “ecological imperialists” (Crosby, 1993) and their successors excluded cattle and people from the protected areas.

Western environmentalists who object to tsetse/trypanosomiasis eradication in Africa often have quite a different attitude to similar campaigns in their own countries. One example is the elimination of malaria, which was present in Europe until the mid-twentieth century. Another example is the campaign against rabies that is now under way on the European continent and which could result in changes to the ecosystem, such as an increased fox population. A third example is the eradication of screwworm fly from North America. It had been predicted that this eradication would unbalance the ecosystem, causing massively increased numbers of deer and other wildlife; in fact, wildlife has increased moderately in some areas. However, the harvesting of this wildlife through carefully managed hunting has not only regulated population numbers adequately, but has also created a large hunting industry which is very interested in preserving these resources and employs, directly and indirectly, hundreds of thousands of people. In many tsetse-affected African countries, natural wildlife resources are considered to be an economic component of increasing importance. The proper management of national parks and game reserves, whether tsetse is present or not, will have to reflect these developments.

Unless tsetse flies are eradicated, they will survive in small pockets by feeding on wildlife as reservoir hosts and will threaten agricultural production in the vicinity of protected habitats. Farmers, who are well aware of trypanosomiasis and its mode of transmission through the tsetse fly, object to the existence of wildlife and forest reservoirs and are likely to take (illegal) steps to eliminate wildlife reservoir hosts and forest habitats for tsetse flies. Some park administrations have reacted to this development by introducing tsetse control measures in wildlife parks so as to protect their wildlife indirectly (Opiyo, pers. comm.) The financial viability of parks and related tourist industries also depends on protecting tourists from tsetse, which is an issue, for example, in the Okavango delta of Botswana.

There are, however, a few supportive methods (other than leaving tsetse in the reserves) that can protect African game reserves. Among these is the erection of effective fence systems around game reserves and arrangements that enable local communities to share the benefits of game reserves, such as the Zimbabwean Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) (ESS, 1998).

In summary, with or without tsetse control or eradication, people in need of food and arable land are tempted to invade wildlife areas. In the long term, the creation of tsetse-free zones and the development and implementation of appropriate land use plans are the only alternatives to the encroachment of agriculture into wildlife areas and may permit a peaceful and profitable coexistence of farmland and protected habitat, including game reserves.

Agricultural expansion and/or intensification

The growth of the human population in sub-Saharan Africa is the highest in the world, averaging more than 3 percent per year (Harrison, 1996) and including extreme cases of annual growth of 5 percent. With such population expansion, total numbers of humans are doubling every 15 to 25 years. Population pressure, combined with the low productivity of present agricultural systems, is forcing people to move into new areas, many of which are tsetse-infested. Nevertheless, the presence of tsetse has not been a barrier to human settlement. Bush clearing to eliminate the habitat where tsetse can survive has been the conventional procedure for addressing the problem of trypanosomiasis transmission. In general, the high demand for agricultural land in Africa will result in farmland being established in close vicinity to preserved areas. In some densely populated regions of sub-Saharan Africa, human settlements and cultivation have already reached the edges of national parks. Arguments about the possibility of the tsetse fly playing a role in protecting natural habitats and wildlife from human impacts have been refuted (e.g. Jordan, 1986; Nagel, 1991).

The elimination of *Glossina morsitans* from most of northern Nigeria not only resulted in agricultural advantages but also was accompanied by environmental benefits. As early as 1948, Hornby (see Ford, 1971) adopted the view that, by crowding people into the fly-free areas, *Glossina* was the principal agent in causing erosion. Tsetse elimination in large parts of northern Nigeria effected a more even distribution of livestock numbers in the area (Bourn, Milligan and Wint, 1986). As a result of this and better rains in the subregion as of 1994 (compared with the previous 20 years), the burden of overgrazing in environmentally fragile areas of the Sudano-Sahelian vegetation zone was reduced, and possibly contributed to a slight reversal of the desertification trend in northern Nigeria.

The cycle of expanding agricultural areas, low productivity, poverty, slow human development and rapid population growth, which results in further expansion into new areas, can only be broken by ensuring that current subsistence agriculture in existing farming areas becomes more productive and is profitable. Demographic trends for several tsetse-affected sub-Saharan countries imply that in the years 2010 and 2015 more than 40 percent and more than 50 percent, respectively, of the human population will live in urban or peri-urban systems (Winrock International, 1992). For various reasons, including land tenure problems, a simple expansion of existing agricultural systems is often not possible and will not suffice to feed people living in peri-urban areas. The introduction of more productive agricultural systems, including improved livestock breeds, will be indispensable. However, crossbred livestock have reduced levels of tolerance to trypanosomiasis, and coexisting with the tsetse/trypanosomiasis problem will not be possible.

Regarding the agricultural demand on wildlife areas, the decision to control or eradicate tsetse would have different implications in different situations: in low- to medium-productive agricultural/livestock systems, control would permit expansion into new areas with previously high tsetse/trypanosomiasis challenge; while in areas under agricultural development, eradication would permit the development of more productive agricultural systems that could reach the required increases in productivity. Eradication would tend to reduce the pressure or need for agricultural expansion into new farmland, as it would primarily result, not in more agriculture, but in more productive agriculture.

According to Delgado *et al.* (1999) a "livestock revolution" is taking place, involving increased livestock and agricultural productivity in many developing countries. Such developments, wherever they are possible, could significantly improve the well-being and livelihoods of many rural poor. The livestock revolution also has profound implications for the environment and public health. Authorities and industry must set up long-term policies, investments and implementation structures that reflect economic and nutritional demands as well as environmental and public health concerns.

Ried's (1999) statement that it is not so much a question of "if" but "how much" trypanosomiasis will affect land use and land cover needs to be seen in the context of these trends. The application of advanced survey and monitoring tools, including remote sensing and GIS-based data storage and interpretation (Thomson and Connor, 2000), will in general permit more appropriate situation assessments and facilitate the development of strategies that ensure an environmentally more responsible utilization of natural resources. Based on this information, corrective measures on land and resource utilization can be taken when necessary. Prior to initiating tsetse/trypanosomiasis intervention campaigns, comprehensive baseline data collection exercises, including the evaluation of available natural resources, the identification of specific indicators and subsequent periodical environmental screenings, are instrumental for early detection and minimization of possible ecologically disturbing land use changes.

Grant (2001) stresses that public confidence in tsetse intervention techniques is being undermined by political viewpoints, fears (often based on misinformation) and poor communication of the environmental issues. It is therefore advisable that stakeholders be involved in environmental assessments and the development of land use plans at an early stage. This could prevent unnecessary misunderstandings and some of the emotional opposition to intervention campaigns on tsetse/trypanosomiasis eradication.

ECONOMIC FEASIBILITY

The most persistent argument made in relation to the use of SIT to eradicate the tsetse fly from strategic areas in Africa is the claim that it is not cost-effective. Under situations that are not area-wide this claim may be justified. A group of experts convened by FAO in 1988 agreed that the technique might be cost-effective, provided that the operation covered at least 20 000 km^2. Obviously, any major campaign in Africa, irrespective of the technique used for sustainable control or eradication, would need to take into account economies of scale and would require considerable investment.

Any investment made will have to be preceded by a benefit-cost assessment. In the case of the New World screwworm fly, the investment of almost US$1 billion that was made between 1957 and 2000 resulted in the eradication of the pest from North and almost all of Central America. The annual direct producer benefits in the previously affected countries amount to US$1.165 billion, and economists estimate that the multiplier effect on the economy is at least three times this amount (Wyss, 1998). In comparison, assuming that over the same 40 years only US$100 million per annum had been spent on dispersed efforts on tsetse and trypanosomiasis research and control, the total would already amount to US$4 billion, without having achieved such a tangible result as in the case of screwworm.

Provided tsetse eradication were achieved, it would invariably be the most attractive option in economic terms (Slingenbergh and Hursey, 1993). The favourable benefit-cost ratio of the accepted conventional approaches would be improved further by a complementary application of SIT. The obvious imbalance between an assumed annual investment of US$100 million for tsetse and trypanosomiasis research and control, and estimated direct losses of between US$600 million and $1.2 billion per year indicate what still needs to be done. Indirect losses in terms of the lost potential and reduced productivity of animals and humans who contract trypanosomiasis – which may be ten times this amount annually – are not even considered. Other costs that are usually not accounted for include the environmental side-effects of continuous tsetse control and the interference with enzootic stability to various tick-borne diseases.

Concerning the environmental and economic costs of pesticide use in the United States, for example, Pimental *et al.* (1992) estimated that an annual investment of approximately US$4 billion saves about $16 billion of United States crops and that the unaccounted environmental and social costs of pesticide use amount to at least US$8 billion each year. The authors emphasize that a complete long-term accounting of all the (direct and indirect) costs of pesticide use would probably reduce the perceived profitability of applying pesticides by approximately half. Based on such expanded benefit-cost assessments, the option of eradication through integrating the (temporary) use of conventional methods with SIT becomes more attractive in economic terms.

Comparing the recurrent investments needed for continuous control and the additional investments needed for a complementary tsetse SIT eradication campaign, it is obvious that the eradication effort requires only that control budgets for a few years are available at once. Based on the current cost of sterile males and assumed average release rates of 100 sterile males per square kilometre, the present cost for the additional SIT package (sterile males + 18 months of weekly aerial releases) is estimated at US$800/km^2. Barrett (1997) lists the recurrent cost of tsetse control using insecticide-impregnated targets in Zimbabwe during the period 1987-1991 at approximately US$100/km^2 (i.e. Z$600 at that time). Budd (1999) estimates the 1999 cost of placing insecticide-impregnated targets in Zimbabwe at between US$220 and $385/km^2, depending on the accessibility of the terrain. According to Allsopp and Phillemon-Motsu

(2000), maintaining the status quo of tsetse/trypanosomiasis control in the Okavango delta of Botswana requires a recurrent expenditure in excess of US$1.5 million per year, although no cases of nagana were recorded between 1985 and 1998, and the last case of sleeping sickness in Botswana occurred in 1983. The treated area comprises up to 6 000 km^2, so the cost for target placements as implemented in Botswana therefore amounts to at least US$250/$km^2$. Based on the two examples above, the implementation of an SIT component for tsetse eradication needs an investment over 18 months that equals two to eight years of recurrent expenditures for tsetse control.

This calculation reflects only the direct expenditures for tsetse control and does not consider the additional benefits accruing from eradication, such as significant increases in livestock productivity resulting from the introduction of crossbred cattle. Such productivity increases, and the concomitant large-scale investments to improve livestock industry, are unlikely to occur as long as tsetse are present – even under a tsetse/trypanosomiasis control situation. The cost of the SIT package will be further reduced by economies of scale, the commercialization of various aspects of fly production (for example, the local collection and processing of abattoir blood as standard diet for tsetse), the ongoing development and refinement of methods that are already partially in use for screwworm and medfly SIT, and economizing on the aerial dispersal of sterile males according to habitats and appropriate sterile male densities or ratios in relation to relic wild flies.

As far as cost is concerned, the real challenge may not be cost-effectiveness at all. Given the scale of the existing losses and related human suffering, if eradication can be achieved and sustained, it will be worth it (i.e. cost-effective) over time. Benefits will continue to accumulate year after year. The real issue is simply whether or not the funds required to eradicate and protect strategic areas can be raised and directed to this purpose. Based on the demonstrated success of SIT against various pest insects, including tsetse, and the continuing (and increasing) losses and devastation from trypanosomiasis, it is appropriate to assess the economics of introducing an SIT component in area-wide integrated tsetse eradication campaigns and to develop a model for assessing the economic feasibility and justification of eradicating the tsetse fly from major priority areas in Africa.

Some critics claim that the economic benefits of eradicating an insect pest population stand or fall with sustaining the eradication or experiencing reinfestation, respectively. With regard to the possibility of pest insects reinfesting an eradication area, even temporary eradication may be economically attractive, provided that the phase of eradication lasts long enough to allow the investments made to be recovered (Mumford, pers. comm.). Mumford suggests that, under such circumstances, the concept of "serial eradication" or repeated eradication campaigns is worth considering. For a number of pest insects, one advantage of serial eradication over final eradication is that it does not require the very expensive inputs needed to prove final eradication, for example, the costs of declaring and certifying fruit fly-free zones in order to permit the trade of fruits (Enkerlin and Mumford, 1997). However, in the case of the tsetse/trypanosomiasis problem, the validity of such a scenario still has to be modelled. In view of the reduced infestation risk (see paragraph on Lower risk of tsetse reinfestation, p. 21) and the desire to introduce more productive (and more trypanosomiasis-susceptible) livestock breeds, the final eradication approach appears to be more easily implemented and sustainable for tsetse than it is for most of the other insect pests against which SIT has been, and is being, successfully applied.

When tsetse/trypanosomiasis intervention areas face civil unrest, an SIT component which involves high-flying aircraft for the aerial release of sterile insects may be the only option for sustaining a certain level of control until conventional intervention can be resumed. Preventing the escalation of major human and animal trypanosomiasis problems would result in tangible benefits in terms of economic recovery and subsequent (agricultural) development, once the civil disturbances cease. The availability of a preventive SIT aerial-strike capacity against increasing and advancing human and animal trypanosomiasis problems would, therefore, result in major economic advantages. This should be taken into account when assessing the economics of investing in subregional tsetse production factories.

Preventive SIT measures against insect pests have already resulted in tangible benefits in the cases of medfly, pink bollworm, screwworm and codling moth. For example, preventive aerial release of relatively small numbers (“thin-filming”) of sterile medflies, conducted over the Los Angeles basin since 1994, has kept California medfly-free. As a result of the sterile flies, any medflies emerging from illegally imported fruits are prevented from becoming established. In comparison with the annual expenditures of about US$40 million for former reactive intervention operations after the detection of outbreaks, the new proactive, preventive SIT approach costs only US$15 million per annum (Dowell *et al.,* 2000).

Considering the (agricultural) development status under which screwworm and medfly eradication resulted in the benefit-cost scenarios described in the previous paragraphs, it has to be pointed out that the tsetse/trypanosomiasis problem is far closer to the root of (agricultural) development in its affected countries than are screwworm or medfly problems in their affected countries. In Africa, the impetus for poverty reduction, the positive impact on livelihoods and the related indirect benefits that are expected to accrue from tsetse eradication and the elimination of the trypanosomiasis problem will far exceed the benefits that accrued to screwworm eradication in the Americas.

Chapter 5

Technical challenges

MULTIPLE SPECIES

The tsetse fly exists in Africa only, but there are about 12 to 15 economically important species. None of these tsetse species is distributed across the entire tsetse belt, each is being confined to specific areas. SIT is based on biologically restricted mating habits, and is therefore highly target-specific. Thus, the SIT component has to address each of the species that is present in a given area. However, it is also known that several coexisting species differ in economic importance, and that large areas of agricultural potential in Africa are threatened by the existence of only one or two species. SIT can be used to combat more than one species simultaneously: for example, three species were simultaneously eradicated in the SIT programme in Burkina Faso (Cuisance *et al*., 1986). This requires adequate production and distribution capacities for each of the species being attacked. Equally important, indications are that usually no more than three or four species are found in a given area in Africa and, in most areas, there are only one of two tsetse species. Most of the important tsetse species have been studied and successfully reared on a small scale at the FAO/IAEA laboratory in Seibersdorf. The application of tsetse SIT in a multispecies situation appears to be more of a managerial and engineering challenge – particularly during aerial release (see section on Automated processing and release of sterile males, p. 43) – than a technical and biogical issue.

SUPPORTIVE TECHNOLOGIES

Questions regarding the isolation of tsetse populations, fly population dynamics, the dispersal of flies into neighbouring areas and gene flow among separate tsetse populations can now be answered using new molecular genetic methods. For example, there is evidence that mating within specific *Glossina pallidipes* populations is random, but that this is not the case between different populations (Krafsur *et al.*, 1997). Knowledge on the gene flow between different tsetse populations, or genetic evidence for isolation, will have implications for planning and implementing area-wide eradication operations and quarantine measures. As population-genetic information is essential for the sound planning of intervention campaigns, an FAO/IAEA Coordinated Research Project (CRP) on Genetic Application to Improve the SIT for Tsetse Control/Eradication was initiated in 1995.

Tsetse suppression methods need to be made more efficient. In some affected areas, suppression will be based on community participation. In less populated or less accessible areas, other approaches will have to be considered, for example SAT, non-persistent insecticides or the aerial deployment of disposable, biodegradable baits (prototypes have been designed and manufactured and pilot field tests were scheduled for 2001). For a few fly species, including *G. austeni* and riverine tsetse flies, better odour attractants need to be identified. This work is part of another FAO/IAEA CRP on Improved Attractants for Enhancing the Efficiency of Tsetse Fly Suppression Operations and Barrier Systems Used in Tsetse Control/Eradication Campaigns.

Effective integrated artificial barriers that protect freed areas from reinfestation need to be developed and tested, and systems and procedures set up to ensure that barrier maintenance is sustainable. Further attention needs to be given to the utilization of GIS-based tools for updating species distribution maps, planning and monitoring intervention measures and implementing land use plans.

AUTOMATION OF LABOUR-INTENSIVE AND QUALITY-SENSITIVE ASPECTS OF THE TSETSE SIT PACKAGE

Over the last two decades, important advances have been made in tsetse rearing. Mass rearing procedures have been developed for seven of the economically important tsetse species, and the membrane feeding system, which eliminates the use of living animals, has been developed. Proven methods for collecting and processing and quality control procedures for blood have beem developed (Feldmann, 1994b), environmental optima for each species have been listed (Feldmann, 1993) and basic tsetse rearing technology using the membrane feeding technique has been transferred to several African insectaries.

In spite of these advances, mass rearing remains the most significant area in which improvements would benefit SIT by making it possible to produce enough sterile flies to cover treatment areas of at least 5 000 to 10 000 km^2 at one time. Conventional tsetse rearing procedures are still very labour-intensive, and many steps in the process require the manual handling of flies (Feldmann, 1993). In the conventional tsetse rearing process, the handling of young colony flies takes a total of 46 percent of the labour time invested (chilling adult emergence takes 23 percent, mating 6 percent and chilling for sex separation 17 percent). Although labour costs in Africa are not high by international standards, present rearing systems must be improved further in order to increase the cost-effectiveness of the production of sterile tsetse flies on an industrial scale, following the example of fruit fly and screwworm SITs. Reducing labour-intensive steps will also reduce handling during quality-sensitive parts of the rearing process.

These aspects of the fly production and release process are a top priority for research and development on the upscaling of tsetse rearing and are included in the activities of a third FAO/IAEA CRP on Automation in Tsetse Fly Mass Rearing for Use in Sterile Insect Technique Programmes. In order to enhance the numbers (millions per week) of sterile flies that will be available for eradication programmes on mainland Africa, varying degrees of automation would be beneficial in each of the areas mentioned in the following sections. In an effort to ensure efficient utilization of the increased number of standard- (high) quality sterile males, attention also needs to be directed to reviewing different routines for the handling and sterilization of males earmarked for release, as described in several SIT projects and related research (Cuisance and Itard, 1973a, 1973b; Curtis and Langley, 1972; Langley, Curtis and Brady, 1974; Taze *et al.*, 1977; Curtis, 1980; Dame, Lowe and

Williamson, 1981; Oladunmade *et al.*, 1990). An example of standardized and internationally accepted insect quality assurance is the manual for quality control of fruit flies (FAO/IAEA/USDA, 1998).

Self-stocking of tsetse into adult holding containers

In the conventional tsetse rearing system, colony flies are separated by sex manually after the emergence of adult flies, and are then transferred to adult holding cages. A method for the self-stocking of young tsetse males and females into fly production containers needs to be developed. This requires the sexing of immature tsetse stages and/or incubation procedures for tsetse pupae that result in well-synchronized adult emergence, thereby facilitating self-stocking through the accurate timing of female and male emergence. Methods of pupae incubation for the standardized emergence of flies earmarked for colony breeding or release were already in use 25 years ago for the release of sterile *Glossina morsitans morsitans* in the United Republic of Tanzania (Williamson *et al.* 1983a, 1983b). A refinement of these methods and improved equipment for standardized incubation led to new routine practices of self-stocking of colony females, and good progress on self-stocking is being made for several tsetse species, including *G. austeni* and *G. pallidipes* (Opiyo, Luger and Robinson, 2000).

Options for early sexing could also involve scanning of the differently advanced pigmentation of male and female larvae within the puparium, or automatically recognizing structures of the male hypopygium (through ultrasound microscopy or capacitance; Soldan, Brunnhofer and Masak, 1999). These methods may have some potential for sexing at the medium and late pupal stages, respectively, but so far work has been restricted to preliminary investigations. This is also the case for the sex separation of tsetse that is based on the abdominal hair pattern of males and females. Computer imaging principles have been identified that may eventually permit automatic separation of adult males and females within less than half a second per fly (Hufnagl, Stubenvoll and Wenzl, 1995). However, these methods still require considerable verification and refinement before they can be integrated into mass rearing procedures.

Automatic holding and feeding of large tsetse colonies

Another process that would benefit from standardization and automation is the holding and feeding of millions of colony females in African tsetse factories. An initial automated prototype proved too sophisticated and did not sufficiently reflect the basic requirements of colony flies. A second-generation tsetse production unit (TPU-2) was tested (Opiyo, Luger and Robinson, 2000) and transferred to a few African tsetse insectaries for methods verification. Based on the experience generated with the TPU-2, a semi-automated third-generation prototype (TPU-3) is currently undergoing trials and shows good promise of reducing the effort of cage handling and the feeding process by approximately 90 percent. A transfer of the TPU-3 for testing and refinement in some African tsetse mass rearing centres is anticipated for 2001.

Automated processing and release of sterile males

More efficient, less expensive and standardized systems are required for sterile male processing (marking, irradiation and dispatch), for the transport of males to release sites and for fly release. Currently, aerial releases are conducted using fixed-wing aircraft or helicopters with sufficient space for the pilot, the release coordinator, the fly dispatcher and the boxed flies. Future release operations should preferably involve the release of unboxed, chilled flies. Such a system, together with a computerized recording system, is currently in use in New World screwworm fly and medfly SIT operations, and a multispecies system is currently under development in California for joint mexfly and medfly releases. In 2000, the development of an automated aerial release system for chilled adult tsetse flies, based on the New World screwworm fly release system and with a new global positioning system- (GPS) and computer-guided release-rate metering capability, was initiated. Several pre-release sterile male processing steps will be standardized and tailored to this new method.

Industrialization of sterile insect production

Standardizing and automating these critical steps would simplify the fly production process considerably and result in large reductions in the cost per insect produced (currently between US$0.07 and $0.14 per sterile male, depending on the species, which investments and expenditures are included and which amortization period is computed). With further cost reductions (in a first phase to a cost of US$0.05 to $0.09 per sterile male), SIT would become an economically attractive package (sterile flies plus aerial releases) for complementing integrated area-wide tsetse and trypanosomiasis management campaigns. Even more important, expansion of the production process to the required industrial level would involve economies of scale and would be feasible with such a streamlined production system. Only at this stage would it become possible to estimate accurately the cost of fly production. Steps are being taken to address these issues in conjunction with collaborators.

Experience with other mass reared insects has shown that, as a consequence of the economies that accrue from industrial-scale production, the cost per insect produced decreases dramatically (by more than 70 percent) owing to the fact that, at large production levels, fixed costs represent a far smaller percentage of total costs. As a consequence, SIT is unique, not only in that it can achieve eradication over inaccessible terrain and in an environmentally friendly way, but also because, on the large scale, it becomes increasingly cost-effective compared with conventional control methods.

Economies of scale are also realized during the initial investment required in mass rearing facilities. Large rearing facilities producing, for example, 1 million sterile males per week are relatively cheaper to build and operate than small ones. In addition, the investment costs for such large facilities are amortized (depending on the item, amortization times of between two and 15 years are computed) over many years and several eradication projects. The productive life of a facility can readily be increased by refurbishing, and one facility can serve successive and/or concurrent programmes. Existing screwworm, Mediterranean fruit fly and pink bollworm facilities are all still producing millions of sterile insects weekly after more than 15 to 20 years of operation. In addition, for tsetse flies, the danger of a facility becoming a useless “white elephant” is limited because of the increasing numbers of requests for tsetse SIT, the number of tsetse species on mainland Africa and the scope of tsetse infestation. After eradicating one tsetse species, a tsetse fly mass rearing facility could, with very little conversion, be adapted to rearing other species. Alternatively, the factory could consist of modular production systems, and additional modules for the production of other species could be added as required. The demand for sterile tsetse flies is assured for several decades, so hundreds of jobs would be created.

There is another essential reason why investment in such large facilities is cost-effective. When large numbers of sterile flies are available continuously, large infested areas can be covered simultaneously at adequate overflooding ratios. As a consequence, large SIT eradication programmes progress much more quickly, and are therefore far cheaper. This was illustrated in the screwworm eradication campaign in the Libyan Arab Jamahiriya, where the initial availability of massive numbers of flies resulted in rapid eradication, thereby reducing the total cost of the programme substantially (Lindquist, Abusowa and Hall, 1992).

Commercialization of blood supply, mass rearing and sterile fly release

Based on the continuous demand that can be foreseen and the need to operate mass rearing facilities efficiently and maintain them properly, commercialization is a reasonable goal. Beneficiaries of sterile insect release programmes are already paying for and influencing SIT campaigns and relevant management decisions (Bloem and Bloem, 2000; Reyes, Santiago and Rhernandez, 2000), and further efforts should be directed at commercializing insect factories. A first step might be for governments to lease insect rearing facilities for certain periods to private operators, thereby simplifying SIT programme logistics and assuring the quantity and quality of the product of a facility. Clean blood is the only biological resource that is continuously required in the tsetse rearing process, and the demand for this product would also encourage companies to provide a regular supply. The release of sterile flies by air is another process that lends itself to commercial operation. A private company under the supervision of programme staff carried out the aerial releases over Zanzibar.

Area-wide coverage leading to eradication, the unique level of environmental acceptability and the potential for commercialization, as well as aerial distribution, all make SIT very attractive. Provided that subregional fly production facilities and aerial dispersal infrastructure are available and pre-release population suppression is conducted on the basis of the area-wide principle, the subsequent introduction of the SIT component is relatively independent of infrastructure on the ground (with the exception of airports, surveys and public relations activities). Therefore, once conventional community-supported pre-release population suppression has reached a certain level, the sterile insect releases can be initiated and no further interference with the operations is anticipated.

Chapter 6

A plan for action

A number of issues need to be addressed when planning the integration of SIT into a concerted effort of area-wide tsetse and trypanosomiasis eradication from parts of sub-Saharan Africa. A coordinated application of different complementary methods, such as the use of conventional suppression techniques applied on an area-wide basis and followed by SIT, would be required. This is particularly applicable to situations where one conventional method has failed to overcome a serious trypanosomiasis problem or the mounting costs of continuous control are no longer acceptable. An area-wide integrated approach with an SIT component is the only concept that offers such a clear prospect for substantial progress.

To ensure sustainable tsetse eradication, knowledge about the actual distribution of the target tsetse species and the degree of isolation of the proposed area is essential. Areas where the flies are biologically or geographically isolated would certainly be more suitable for both eradication and subsequent quarantine, and initial tsetse eradication efforts should focus on supporting agricultural systems in such zones.

The implementation of larger-scale, transboundary tsetse eradication campaigns requires an efficient, well-organized operational unit of managers and specialists who are not affected by the bureaucratic procedures of governments and regional or international organizations but, nevertheless, have the full support of the top decision-makers of affected countries and other major stakeholders.

The advancement, promotion and implementation of SIT as a component of integrated, area-wide campaigns requires parallel and balanced efforts in the following three areas:

- *Awareness, support and funding issues:*

- In order to obtain the collaboration and support of the governments and institutions of tsetse/trypanosomiasis-affected countries, international bodies, potential donors and the private sector should increase general awareness of the potential and advantages of the available package of area-wide intervention and the SIT component for tsetse and trypanosomiasis management.
- The international community should support a process of policy and strategy revision in tsetse- and trypanosomiasis-affected countries.
- Research on, and interventions against, African trypanosomiasis need intensified support and prioritized coordination. Strengthened efforts are needed to ensure the compatibility of systems, materials and methods and the complementary utilization of available expertise and resources.
- It appears essential that specialized agencies of the UN family and other partners support a transfer of ownership of the tsetse/trypanosomiasis problem and of initiatives directed at its alleviation and elimination to “problem holders” and African decision-makers. Furthermore, OAU must receive appropriate technical and other assistance in its efforts to develop and periodically revise a detailed action plan that is relevant to the African Heads of State and Government decision on tsetse eradication (AGH/Dec.156 [XXXVI]; OAU, 2000; PAAT, 2000). These efforts include the development of an efficient management structure, and operational rules and practices that are tailored to the specific needs of an area-wide insect vector intervention programme.
- Donor countries should be provided with evidence that, in order to address one of the roots of poverty, it is in their interest and should be part of their strategies to invest in tsetse/trypanosomiasis eradication campaigns. They also have to be convinced that a prerequisite to establishing profitable markets and trade in developing countries is the prevention and spreading of human disease and the preservation of natural resources in Africa.

• *Technical issues:*

- Intensified subregional tsetse and trypanosomiasis surveys, together with the collection of other relevant information, are essential. Such information should be incorporated into appropriate data sets and transformed and disseminated in the form of geo-referenced databases. For ambitious eradication undertakings, it is also expected that new molecular genetic and biochemical techniques could be used to complement the survey efforts, thereby enabling a better understanding of tsetse population dynamics and the interaction between neighbouring fly populations. Thus, isolated or well-confined tsetse "pockets" and "peninsulas" could be identified and tackled one by one.

- Priority areas should be screened and criteria for intervention defined in consideration of economic and environmental impact predictions. This applies to expanding (low- and medium-productivity) and intensified livestock systems.
- Using advanced GIS and specially developed databases, opportunity areas for the application of area-wide tsetse/trypanosomiasis interventions with an SIT component should be identified. Such efforts should focus on a few pilot areas and aim to generate success stories of creating, and subsequently expanding, tsetse fly-free zones in areas where this is predicted to have a substantial economic impact.
- After careful consideration of the relevant data that emerge from detailed feasibility assessments, and with the approval, support and participation of the respective government authorities, international organizations, donors, affected communities and the private sector, a detailed feasibility demonstration of a few selected programmes aimed at the creation of large tsetse fly-free zones in the region should be conducted. Such demonstrations would include all of the aspects that are relevant to the planning and management of an integrated area-wide campaign and to tsetse eradication, including effective handling of a multispecies situation, automation of the rearing process, logistics and post-eradication quarantine. The participation of other partners in the planning and execution of the programme is important, including during the initial suppression of

the wild fly population and during post-eradication agricultural development.

- New semi-automated and standardized processes for fly production should be introduced into several African insectaries for testing. Private enterprises with established competence in industrial design and other aspects to be addressed should be approached to collaborate on designing, testing and servicing the equipment needed for improved, upscaled tsetse factories. Meanwhile, support to existing mass rearing centres that apply the new mass rearing procedures should be strengthened to ensure that African Member Nations' needs for sterile tsetse fly males can be met.

• *Normative issues:*
  - Based on detailed economic, social and environmental evaluations of the phased, integrated and area-wide approach, and particularly the SIT package (fly production and aerial dispersal), models should be developed to assess the feasibility and sustainability, as well as the economic aspects, of the creation and expansion of tsetse-free zones in various other opportunity areas.
  - Criteria such as the availability of staff and spare parts, the reliability of electricity and water, repair services and flight connections to customers, and support from national authorities (Feldmann, 1994a) need to be developed in order to select the optimal locations for subregional tsetse mass production factories. The existence of such factories and the availability of private contractors for the release flights are key prerequisites when offering interested customers the SIT package, i.e. sterile males and aerial releases.
  - Procedures and standards need to be developed and internationally agreed as the basis for, often transboundary, quarantine measures (barrier systems against tsetse reinfestation) that will eventually permit an internationally accepted declaration of tsetse fly-free zones.

Chapter 7

Conclusions

Sustainability can be achieved through:

- sustainable (continued) tsetse and trypanosomiasis management activities, which are the objective of the community-based approach of living with a controlled problem; or
- sustainable results (fly-free zones), which are the objective of an area-wide integrated tsetse eradication effort with an SIT component.

The environmental advantages of SIT over other methods are obvious because non-target organisms are not affected. Tsetse eradication does not cause a decline in biodiversity and will tend to limit agricultural expansion.

The development option that results from tsetse eradication, i.e. agriculture that is far more productive, is economically more attractive than the option resulting from control, i.e. expanded low-productivity agriculture that requires the continuous opening of new areas to agriculture.

The technical feasibility of using SIT for tsetse eradication and elimination of the trypanosomiasis problem has been demonstrated. The technology is more suitable and the risk of reinfestation is lower for tsetse than they are for screwworm, medfly or most other dipterans.

Some technical challenges need to be addressed in order to make tsetse SIT more cost-effective.

The following main issues regarding the acceptance of the area-wide tsetse SIT approach are of an economic nature:

- Provided that the tsetse suppression activities follow the area-wide principle, the complementation of ongoing tsetse/trypanosomiasis management activities with an SIT component for tsetse eradication needs an investment over 18 months that equals two to eight years of recurrent expenditures for tsetse control.

- The development potentials that result from tsetse control and tsetse eradication are different. Control in areas with previously high tsetse/trypanosomiasis challenge generally supports the expansion of existing low- and medium-productivity agricultural and livestock systems from neighbouring lower-challenge areas into the newly controlled areas. Eradication from areas that are under agricultural development, together with appropriate land use planning, paves the way for an increase in productivity and a diversification of agricultural production.
- The direct producer benefits that result from a total investment in New World screwworm eradication during the period 1957 to 2000 of less than US$1 billion amount to more than US$1.15 billion per year. The subsequent annually accruing overall benefits can be assumed to be at least three times this amount. As tsetse/trypanosomiasis is far closer to the roots of (agricultural) development and poverty in Africa than screwworm is to the roots of development in North and Central America, more benefits in relation to investments made are expected from tsetse/trypanosomiasis eradication.

Partners collaborating in the exercise need to ensure the transfer of ownership of the planning and implementation of action against tsetse and trypanosomiasis to African decision-making bodies. The real challenge that remains is to focus governments' and donors' awareness on the problem and on developing the capacity to implement an integrated area-wide approach. Only a long-term commitment from governments and donors at the regional or subregional level will have a sustainable impact on tsetse distribution and the trypanosomiasis problem in Africa.

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