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9. ABSTRACT
This report assesses a project jointly sponsored by A.I.D. and the United Republic of Tanzania to determine the effect of the sterile insect release method on the tsetse fly population in Tanga, Tanzania. This project tests the SIRM under controlled circumstances. Advances in tsetse fly biology and fly sterilization techniques indicate that the tsetse fly may be susceptible to control by the SIRM in combination with other methods. The SIRM may also become an important maintenance control method. This experiment will provide the necessary guidelines for future large scale operational programs. The information collated in this report is derived from the team's assessment of: the existing ecosystem, the activities that might have beneficial or deleterious effects on the environment, the types and levels of pesticide and herbicide application, the effect of the treatment on the ecosystem, the direct social and economic implication of the SIRM on animal and human populations and how an understanding of the basic science of tsetse fly eradication can contribute to ecosystem management. The team concludes that the tsetse research project will have negligible detrimental impact on the environment. The bulk of the report is the appendices which include information on precipitation, geology, the mammals, birds and reptiles of the area, a literature review, plant communities and cover types, a plant list, a review of insecticides and application equipment, and a bibliography. Given the successful conclusion of the SIRM, future tsetse fly eradication projects may be undertaken with a 40-50% less dependence upon insecticide applications.

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AID/TA/AGR
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TO : TA/AGR of the Agency for International Development
U.S. Department of State

FROM : The Environmental Assessment Team of the Tsetse Research Project, Tanga, Tanzania

DATE : April 1, 1977

SUMMARY STATEMENT : The Environmental Assessment Team has concluded that the Tsetse Research Project, Tanga, Tanzania will have negligible detrimental effects on the environment of the Project Laboratory at Tanga and the field test site at the Mkwaja Ranch. As a result, given the successful conclusion of the Sterile Male Insect Release Method, future tsetse fly eradication projects may be undertaken with a 40 to 50% less dependence upon insecticide applications.

THE TSETSE RESEARCH PROJECT -- AN ENVIRONMENT ASSESSMENT

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I. INTRODUCTION

The U.S. Agency for International Development (AID), Department of State, in accordance with the National Environmental Act of 1969 published "Environmental Procedures," Amendment 216 in the Federal Register, Volume 41, No. 127, 1976. The Amendment insures that environmental factors and values are integrated into the decision-making process of AID program actions. This report describes AID's first step in implementing the new amendment, an environmental assessment of the TA/AGR Tsetse Research Project on the Sterile Insect Release Method (SIRM) that is currently being conducted in Tanga, Tanzania. The Project is jointly sponsored by U.S. AID and the United Republic of Tanzania.

The Rules and Regulations of Amendment 216 provide for exemption from environmental assessment of "controlled experimentations confined to small areas and carefully monitored." Although the Tsetse Research Project may well meet the requirements for exemption, AID has elected not to apply the provision. The Tsetse Research Project was initiated in 1966 and therefore the absence of an initial impact statement (see 216.3 of the Rules and Regulations) has meant that the assessment team did not have the benefit of the evaluations from other Federal Agencies which for future programs may be available.

The environmental assessment team was appointed in the fall of 1976. It conducted a literature search in the U.S., convened a preliminary planning session and soon thereafter, undertook an on-site visit in January of 1977. AID requested the assessment team to provide AID and the Host Country with a comprehensive statement of the reasonable foreseeable environmental effects of the SIRM as a component of an integrated tsetse fly eradication program at Mkwaia Ranch. The assessment team was also asked to consider technically viable alternatives, so that the expected benefits of development objectives could be weighed against any adverse short or long-term impacts upon the total environment or against any irreversible or irretrievable commitment of resources.

The Tanzania-AID Tsetse Research Project is an experiment to test the SIRM under controlled circumstances. Advances in tsetse fly biology and fly sterilization techniques indicate that the tsetse fly may be susceptible to control by the SIRM in appropriate combination with other methods of reducing the fly population. It is also possible that the SIRM may develop into an important maintenance control method. The success of failure of the experiment will provide the necessary guidelines for future large-scale operational programs.

The assessment team undertook to: (1) describe the existing ecosystem; (2) delineate activities that might have beneficial or deleterious effects

on the environment; (3) assess the type and levels of pesticide and herbicide application; (4) anticipate the effect of the treatment upon the ecosystem; (5) assess direct social and economic implications of the SIRM on animal and human populations; and (6) assess how an understanding of the basic science of tsetse fly eradication can contribute to ecosystems management. The information thus derived has been collated in this report for concerned persons in the U.S. and Tanzania.

We wish to thank the staff at the Tsetse Research Project in Tanga, the management of the Mkwaja Ranch, the Department of Zoology at the University of Dar es Salaam, and the Ministry of Agriculture in Tanzania for their cooperation.

A. PROJECT RATIONALE

Tsetse fly infestation in Africa is considered a major constraint to the full utilization of large areas for agricultural livestock production. Infestations of the tsetse fly have precluded human and or livestock occupation of approximately 10 million square km. in Africa. There are several types of trypanosomes, but the major ones cause Nagana in cattle, and sleeping sickness in humans.

With regard to Africa, the World Food Conference in Rome in 1974 declared that "trypanosomiasis and tsetse fly control must be the first phase of an integrated plan of economic development." The declaration was given urgency in the United Nations study on the Future of the World Economy (1976). The Report argued that "the major thrust of food supply in the developing regions will have to come from an increase in their own agricultural output but even after mobilizing available excess arable land resources, the land productivity (including crop yields and cattle productivity) would have to be increased at least three-fold in the developing regions if the 5 percent annual agricultural target is to be realized."

The Tanzanian Ministry of Agriculture ranks animal trypanosomiasis second only to East Coast Fever among the livestock diseases which hinder development. It estimates that 60% of Tanzania is infested by the fly.

In the past, methods for controlling the tsetse fly have included large scale clearing of natural vegetation on which the flies depend for shelter, killing of indigenous wildlife on which the flies depend for food and, more recently, use of insecticides and herbicides. According to (J. Ford, 1976), "in Africa as a whole, one estimates that, since large scale attempts to eliminate tsetse fly were begun in about 1925, total success may have reached about 1.5% of the infested areas, but

that almost certainly this has been more than balanced by reinfestation of formerly fly free land". With an increasing population requiring increased food supplies at the same time that environmentalists are forcefully making the case for the preservation of natural ecosystems, research activities in biological control measures have been greatly stimulated. The most promising lead to date is the sterile male release.

In the case of the tsetse fly, the SIRM introduces within the environment active tsetse flies who have been rendered sterile by irradiation. A preponderance of sterile males can virtually halt the reproductive process of a natural fly population in a predictable period of time. Since 1963, U.S. AID has supported research on the development of techniques necessary for suppressing Glossina m. morsitans the species of tsetse which is a principal vector of animal trypanosomiasis in East Africa. The research has been conducted at Tanga, Tanzania.

The objective of the Tanga Project is to determine the efficacy of using sterile males for tsetse fly population control in an area protected from reinfestation. The questions to be resolved are whether a sufficient number of flies can be reared in the laboratory, sterilized, transported, and released so that the flies disperse and effectively compete with the males of the natural population.

B. PROJECT FACILITIES AND THE TEST SITE

The fly rearing laboratory for the Tsetse Research Project is located 3 km. west of Tanga, Tanzania. The facilities consist of a rearing station, laboratories, and headquarters for the administrative staff. Construction began in June 1972, and the third insectary was completed early in 1977 In addition to the three insectaries, there are associated animal sheds, animal quarantine buildings, and an irradiation complex. The 8 hectares surrounding the buildings serve as the animal paddocks and the forage crop production area.

In addition to the routine rearing of flies and animal husbandry, the 126 member staff has developed methods for handling, sterilizing, and transporting the tsetse flies and is conducting ecological studies of the field site. The staff plans to assess the density and distribution of the natural fly population, the fertility of the fly population treated on the ranch, and the disease incidence among wild and domestic animals.

Mkwaja Ranch field site for the Tsetse Research Project, is located 100 km south of Tanga, Tanzania (38° 41.5'E, 5° 45'S). The Ranch has operated under the Swiss management of the Amboni Sisal

Estates, Ltd since 1953. Approximately 12,000 head of commercial cattle graze the ranch which consists of a coastal woodland-savannah vegetation mosaic varying from open grassland to dense thicket and high forest. The ranch is divided into northern and southern sections (see Figure I). The northern section covers about 260 sq. km. and is the site of the research program; the southern section is slightly smaller and serves as the untreated control area.

Tsetse files (G. morsitans, G. pallidipes, and G. austeni) inhabit the ranch and transmit animal trypanosomiasis to the livestock. Human trypanosomiasis does not occur on the ranch or in the surrounding area. Four times each year the livestock receive prophylactic treatment (isometamidium) to prevent trypanosomiasis and in addition they are dipped weekly in toxaphene to control tick-borne diseases.

Since the beginning of the ranch operation, several programs have been undertaken to control the tsetse fly. However, today the tsetse flies are present in even larger numbers than they were originally. Importantly, moreover, G. m. morsitans, which was not detected earlier, has become a dominant tsetse species. Past experiments with insecticides and partial barrier clearing have failed; the only new element to be introduced into the environment by the Project is the sterile male fly. These conditions, together with the large number of cattle at risk, make the Mkwaja Ranch an ideal site for the field trials.

C. PROJECT SCHEDULE

The Tanga Tsetse Research Project was conceived in three phases. The first phase, now successfully completed, was to establish a captive colony of G. m. morsitans. The second phase is to expand the colony so as to produce sufficient numbers of flies for sterilization and release. The third phase is to complete the ecological studies and field operations for the suppression or eradication of the tsetse fly in a test area of about 260 square km. The colony of G. m. morsitans at Tanga is the largest colony of a single species of tsetse fly in existence. The colony will reach the level of 45,000 females and 15,000 males sometimes between June and September of 1977, making available between 800 and 1200 males for daily release. These numbers will permit a daily release rate of 3 to 6 flies per square km.

The present conception of the release technique is based upon letting the bulk of the females emerge at the rearing laboratory (females precede males in emergence) and cooling the remaining pupae (mostly males) for transport to the Mkwaja Ranch where they will be irradiated and released prior to emergence as adults. The release of the sterile males will follow two or three aerial applications of endosulfan designed to reduce the tsetse fly population to a manageable level. The releases

will continue for 16 to 20 months. The effectiveness of the treatment will be monitored by routinely assessing the fertility and population density of the target species, G. m. morsitans, and the density of G. pallipides. The adjoining section of the ranch will serve as the control area and will not be treated. The Tanga Tsetse Project is expected to be completed by the end of FY 1979.

II. THE EXISTING ECOSYTEM

A. THE MKWAJA RANCH

Description of an ecosystem requires comprehensive consideration of the interaction between living and nonliving portions of a natural unit. In order for the whole interlocking mechanism to function as a natural community, its various components must be present in sufficient approximation of working harmony to permit normal growth and replacement of the constituent plants and animals. Examples of the nonliving components of an ecosystem are energy, water, essential minerals, and atmospheric gases. Examples of the living components are forage and food producing plants, food producing animals, organisms which aid in recycling, and the dominant species which create the general character of a landscape. It is necessary that all these materials and processes be compatible if an ecosystem is to approach its proper rate of productivity. Removal, stress, or ill health of the important participants can reduce production of materials or cause the natural resources present to diminish.

At the Mkwaja Ranch, the elevation, topography and soils vary and these differences represent distinctive ecosystems. The past and present land use has determined the natural communities as they are described in this report. The general setting for the regional environment has been ably presented in The Natural Resources of East Africa (Russell 1962). Another important reference is the Atlas of Tanganyika (1956). Specific source material will be cited in developing the discussion of separate environmental elements.

Since the establishment of the Mkwaja Ranch in 1953, the management has tried to control the tsetse fly by barrier clearing and use of insecticides. Livestock productivity depends, however, upon chemoprophylaxis and drug treatment as the most effective ways to combat trypanosomiasis. Because of the ranch's professional management and experienced employees, this ranch operation represents, as T. Ford and E. Blaser wrote in 1971, "a large scale field experiment" in commercial livestock production in the semiarid regions of East Africa.

Prior to the ranching operation, the land had been unoccupied because of the low rainfall and the generally poor condition of the soil.

It is representative of many other areas where farming cannot be productively undertaken, but where livestock operations could be maintained. The Mkwaja ranch manager described the major constraints to improve livestock productivity as, first, the tsetse fly, and second, pasture maintencance in the face of the rapid bush regeneration. Forage quality is also a problem and varies from season to season.

The Mkwaja ranch employs 200 workers who, together with their families constitute essentially the total present population of 600. All the settlements on the ranch are related to its operation. Approximately half of the workers and their families have resided on the ranch for over ten years. The other half, primarily herders, come and go frequently. The job of herding has low status and the turnover is so great that it is constant source of frustration to the management.

Almost all settlement services are provided by the ranch. The first ranch school was opened 18 months ago by a teacher provided by the government. Only first and second grades one offered, and children must go to the neighboring village 8 km distant to continue their education. Some 40 children on the ranch reside in small settlements near the corrals or bomas and do not receive any scholling. In compliance with the government campaign that was initiated two years ago, the ranch management embarked upon a massive reading program for adults. Every worker who could read was excused from work two afternoons a week to engage in teaching. This effort lasted for about a year; at its completion, the literacy rate had risen from 30 percent to 90 percent. Other services provided by the ranch are housing, water, and minimal health care.

The ranch organization is atypical. It is the only ranching operation in Tanzania which as remained under private ownership. Although the ranch has invited neighboring farmers with cattle to take advantage of insemination and disease control procedures, there has been little response. The role of the Mkwaja Ranch in training and providing regional leadership is disproportionately small in comparison with its substantial experience in livestock production.

Figure I shows the ranch and the surrounding areas. The ranch area occupies the width of the coastal plain and is divided into two sections, north and south. The Tsetse Project field site is an irregular square between the Indian Ocean on the east and the East African Railway on the west going north from Dar es Salaam to Tanga. Along the north side of the ranch lies a fairly dense mountainous high forest; to the south is the control area of wooded grassland which resembles much of the test site uplands. Between the ocean beach and the ranch is a strip of scattered small plots cultivated by subsistence farmers. The nearby villages are occupied by member of the Zigua tribe. About 5 km to the

northeast of the ranch begin the extensive estates of sisal, cashew and coconuts.

1. Non-Living Components of the Environment

Physiography: The coastal plain at the Mkwaja Ranch release site is a flat, narrow belt of consolidated sands extending inland about 20 km to the toe slope of the escarpment that raises to the Masai plains some 70 km distant. Elevation on the site varies from mean sea level near the mouth of the Msangazi River, containing brackish tide water, to high points of about 100 m on the central east-west ridge that transverses the ranch; approximately half of the ranch area lies below a 65 m contour. The Msangazi River flood plain which courses through the northern part of the ranch does not exceed 40 m in elevation. The lower oceanside portion is a slightly raised, level plain that does not exceed 50 m above the mean sea level. This nor-south strip occupies the eastern 25% of the ranch.

Climate: This tropical region is characterized as having high humidity, an annual rainfall of 800 to 1200 mm, and mean annual temperature ranging between 24° and 32°C. From the requirements of plant growth, the area has a subhumid tropical climate; however, the potential evaporation and moisture deficit is high during the dry seasons, altering the climate of semi-arid conditions at times. Rainfall patterns at the ranch are typically bimodal. The 21-year average annual precipitation is 1,008 mm; however, rainfall is erratic as in many places throughout East Africa. Beginning in 1969, six out of eight years recorded an abnormally low rainfall.

Averages for the 21-year record period as well as for the moist and dry segments are given in Appendix A. When analyzed, these figures show apeak for long rains in April and short rains in November. The corresponding low points in the dry season occur in August and again in February. Humidity remains high except during the mid-day period of direct overhead solar radiation, and the corresponding period of relative humidity sometimes reaches as low as 35 and 40 percent for several hours (see Appendix A).

Parent Material and Soils: The substratum underlying the coastal plain is a combination of coral rag, sandstone, and some limestone (Atlas 1956). The first 5 km inland from the coast contains underlaying of Quarternary alluvium; the next 10 km band contains Quarternary sediments. Deeper marine sandstones and limestones date back to the Jurassic period. The east central uplands of the ranch are suspected to have been caused from a raised Plaistocene reef. Upland soils consist mainly of gray and red orange loamy sands; flood plain alluvium found along the Msangazi

River consists of gray to dark gray "black cotton" soils. Soils of the eastern coastal plain are loosely consolidated and form shallow sandy drainageways coursing south and eastward toward Mkwaja village. The greyish cast is a humic layer to a depth of about 25 cm. This humic layer is also present throughout most of the uplands except on steeper slopes. Below this depth is a red-orange sandy loam. Bleached greyish brown sands, occur in areas of recent erosion and on steeper slopes. Finer, light-colored sandy clay loams of the Msangazi flood plain and along lower portions of the alluvial flats show heavy contraction cracks in rain pond relief. Along the south eastern upland, soils grade from rather well consolidated grey-brown surface sands in the north central portion to poorly consolidated red-orange sands in the southeastern corner. Where the central uplands break toward the Msangazi River to the north and west, grey sands again become higher in color; this reflects more rapid geological erosion from the steeper slopes. Isolated outcropping of coral rag can be found at or near the surface throughout the southern parts of the ranch.

Water: For several months following good rains, the Msangazi River maintains a continuous course across the ranch. Other larger drainages such as the Chogera tributary, which drains the northwestern extension and a few rivulets in the southeast corner also flow following the November-December and March-April rainy periods. Large earthen dams provide year round water for cattle and game. There are 65 dams; 40 are presently functional which is unusual considering the loose sandy soil texture. During the dry season only the largest dams retain water and frequently water is hauled from a distance of up to 32 km. There are 15 good reservoirs, some in excess of five hectares. Attempts at exploiting subsurface water have not been successful. Salt water is all that has been obtained from the several previous borehole attempts. At the present time a borehole is under construction on which an accurate log is being kept. The prospects for this 41 m well appear to be favorable and will provide hydrological information of this little surveyed region south of the Pangani River.

Atmosphere: Atmospheric conditions, apart from the climate, consist of air movement patterns and particulate suspensions, both natural and man-made. As to the latter, except for somewhat excessive daily cattle trailing to and from the corrals (bomas) and the necessary administrative vehicular travel, no man-made agents are produced which escape into the air. Natural agents consist of wildlife induced carbon particles and associated oxides from burning herbaceous and woody materials. The uncontrolled fires are usually caused by man but on a sufficiently routine basis to be considered a normal or "natural" phenomenon. These fires are much reduced and less frequent than earlier years when the ranch was undeveloped land. Formerly, wildlife begun through the coastal plain highgrass and consumed all but the most resistant woody species during both the short and long dry periods each year. Lightening undoubtedly was an agent in the large scale firespread, but under present

range grazing conditions is of less significance. So called wildfires contribute nearly all smoke particulate matter except that from wood fires needed for meals preparation by the ranch household.

Wind patterns follow a prevailing westerly path from the ocean and are stronger during the February - March short dry season than during the July through September long intermonsoonal period. Daily wind (1100-1600 hrs.) movement is highly irregular with strong drying mid-day winds dimipishing to near calm between 2200 hours and daybreak. Mid-day extremes might approach 25 to 35 km per hr), while normal movement is between 10 to 20 km hour. Upper level storm patterns can originate from inland convection patterns but the monsoonal begin at sea. Storms produce intensely heavy rain of short duration which, when occurring on dry or super saturated soils, produce large volume run-off with accompanying sheet and gully erosion. These high run-off situations are aggravated by the excessive removal of ground cover caused by cattle, trailing, grazing and fire.

2. Living Components of the Environment

The topical subhumid coastal climate produced by the equatorial latitude and coastal geography has furnished a diverse ecosystem of plants and animals. Most of East Africa is geologically old, with plant and animal evolution and speciation having proceeded uninterrupted relative to the general situation in the temperate zones. In spite of more recent geological changes along this eastern coastal region, plant and animal speciation and distribution show a mixture of interior ecosystems with that of the marine and oceanic environments.

The impact of the ranching operation has not radically altered the fauna or flora so as to exclude many, if any, species. Perhaps the greatest change which has resulted from twenty years of domestic grazing animals has been the rapid encroachment of woody vegetation. In the past, the high volume of grass fuel for repeated burnings prevented bush establishment and maintained only fire tolerant species. The recent efforts to suppress range fires and the effect of livestock grazing have resulted within a short time period in the invasion of bush and the consequent mobilization of much of the nutrient capital of the basic soil productivity.

These vegetational changes have altered the composition of the dependent animal communities. This is not to say that any species of animals or plants have necessarily disappeared; on the contrary, some existing or new species may well have acted as invaders or actually increased their presence. Wart hogs and perhaps waterbuck are examples of species which have been favored by the livestock occupation.

Animal Field Inventory Procedures: During the six day survey period, the range ecologist logged all large animal species observed in order to approximate the biomass. Bass data included date, time of day, route traveled, kilometers traversed and the number of animals by species. Gender was noted when detected. The total of 23.5 hours of daytime observation represented a normal distribution of morning, midday and evening hours. More species were observed during morning and evening activity periods than during the midday periods. This was particularly true in cases of the ruminant ungulates. During the field inventory 373 km of primary and secondary bush track were tranversed. In addition, cross country travel and foot safaris were undertaken to observe plant and animal communities throughout the entire ranch. Animals recorded during the inventory constitute about 40% of the species known to reside for at least part of the year on the ranch.

Animals not seen but known to be present, such as the elephant and buffalo, would add considerably to the biomass. The field inventory and the complete list of larger mammals, birds, and reptiles known to occur on the ranch are given in Appendix B.

Plant Communities: Appropriately, the translation for the Swahili word Mkwaja is the locally conspicuous tamarin tree (Tamarindus indica). Unfortunately, this is where a simple approach to identification and classification of East African coastal vegetation ends. Although a number of classification schemes has been suggested for East African plant communities and ecosystems, none has yet been generally accepted or has stood the test of time. The in-local classification is the physiogomy or plant structure and the surface area coverage by the dominant woody species.

In view of the variation in local methodology and the nature of this in-local tsetse fly habi-at, it was decided to combine the best features of several systems in use and develop a classification method which would meet the specific objectives of this assessment. A review of the literature upon which the assessment method for typing and map preparation was drawn is found in Appendix C.

Limited time precluded a detailed inventory listing of all six types of species components. However, major trees, bush, and grass associations are presented and discussed in Appendix D. The field survey was essential for the analysis of the 1976 aerial photos and the subsequent preparation of the map. Our general interpretation followed the scheme of land units (coastal plain-bush grassland) proposal, Christan (1958). Gillman, who was perhaps most familiar with Tanzanian vegetation, broadly mapped the Mkwaja region as bushed grassland (1949). The assessment team analysis identifies the field site for the Tanga Tsetse Project as four major and three minor land units and associated vegetation cover types.

1. Evergreen grouped tree grasslands found generally throughout the western and southwestern uplands.

2. Mixed (deciduous-evergreen) wooden and/or bushed grassland interspersed between the above forest islands and making up a large part of the northwest extension.

3. The Doum palm-high grass savannah found in the eastern coastal lowlands.

4. Doum and Borassus palm-high grass found in the alluvial flood plains of the Msangazi River.

The minor types which occur in addition to these units may be identified as riverine gallery forests of the Msangazi River and tributaries, the high mixed (evergreen-deciduous) forests of the northern and northwestern mountains, and secondary bushland thickets.

B. THE TANGA REARING LABORATORY

The Tanga Project employs 126 individuals, of whom five are expatriates. The senior staff includes four entomologists, a veterinarian, and a rearing specialist. There are 2 research officers, 3 field officers and 14 assistant field officers with government certificate training. The remaining employees are laboratory and field assistants drivers and support staff.

The construction of the insectaries began in June of 1972; and the third and final insectary was completed in early 1977. All facilities are simply designed and, except for the importation of scientific instruments, have been built with local materials. The complex consists of the three insectaries, associated animal sheds, animal quarantine buildings and the irradiation unit. The 8 hectares surrounding the building serve as the animal paddocks and the forage crop production area.

The insectaries are designed to house 60,000 flies capable of producing 30,000 males per month. Approximately 490 goats and 115 rabbits are maintained as hosts for the flies. The Tanga laboratory uses only blood of living animals. A method for feeding colonies of tsetse flies on blood presented through artifical membranes has recently been developed in Europe, but was not available when the Tanga Project was initiated. In the future, however, the costs of mass-rearing flies will be much reduced by the use of membrane feeding.

A research program such as the Tanga Project does not have a primary responsibility for training. However, the on-the-job training is excellent and must be judged as a significant contribution albeit an indirect benefit. The laboratory is rearing flies successfully with a staff (average age 20), only a few of whose members have had more than seven years of formal education. As the project leader pointed out, if training is neglected at the research stage, when the project becomes operational trained manpower will be scarce. The conclusion reached from observing the management and work disciplines of the Tanga Laboratory is that training, intermediate and advanced, must be a component both of research programs and operational programs.

The Tsetse Research Project has developed good contacts and exchanges with other institutions in Tanzania; however, it would have been desirable if the initial funding of the Project had permitted a more flexible and innovative outreach program. For example, students from national educational institutions would have profit from short-term training fellowships as well as opportunities to conduct research projects under the joint supervision of the Tanga Laboratory scientists and the host country institutions.

The Project is to be commended for the preparation of a brochures in Kiswahili. The Project has developed a working relationship with the International Atomic Energy Agency and the Food and Agriculture Organization and The Tsetse Fly Research Laboratory at Bristol, England. Informal relationships have been maintained with the ICIPE and ILRAD in Nairobi.

III. THE ENVIRONMENTAL ASSESSMENT

A. PROCEDURES

The measures and procedures used by the team to weigh the adverse and beneficial impact of the Tsetse Project were based upon the identification and estimates of the effect of insecticides, and herbicides, bush clearing, and the release of sterile male tsetse flies upon the fauna, flora, soil, water, and atmosphere of the test site. These impacts were evaluated from the perspective of the proposed control of *G. m. morsitans* at the field site and the utilization of the rearing facility in Tanga . The separate impact were not weighed, and, therefore, no comparisons were made of their relative significance.

The team notes that the present environment assessment cannot resolve all the complex socio-economic issues surrounding the mounting of integrated tsetse fly control programs, including the SIRM, over large land areas in Africa. The analysis and prediction of the impact upon human population are considerably more difficult than the technical

analysis of the impact of the control techniques themselves. Information is simply not available as to how the present populations, often already abused and impoverished, will respond to new situations brought about by new technologies. Thus, in its socio-economic evaluation, the team has limited its assessments to those that could be made with a high degree of confidence and has indicated the limitations in the analysis.

The estimated environmental effects of specific projects activities are summarized below. Each aspect of the tsetse fly program at the Mkwaja Ranch and the Tanga Rearing Laboratory has received a separate evaluation.

B. EXPLANATION AND SUMMATION

1. Barrier Clearing: The Mkwaja Ranch management had cleared a one km wide barrier of trees and shrubs around much of the ranch in order to reduce the migration of tsetse flies from the surrounding areas. The Tanga project is presently engaged in completing the barrier. Clearing operations will be limited to the barrier zone. In previously cleared sections, the barrier has become open grassland, and it is anticipated that the entire barrier zone of 65 square km will be covered by grass when the operation is completed. If the grassland barrier is to be maintained and erosion to be prevented, the ranch management must continue to invest in the barrier clearing.

2. Application of Herbicide to Portions of the Cleared Barrier: Following the clearing operation, the herbicide Tordon 155 will be applied to control vegetation regrowth. The herbicide will be hand-applied by brush onto the stumps to avoid general contamination of the soil. The treatments will prevent regeneration and, in turn, the reestablishment of insect and avian population that had inhabited the localized environment.

The effect of the clearing operations on the vegetation is clearly high but at the same time it is very localized. Similar local but rather strong effects will modify certain conditions in the animal community (invertebrate, avian, and mammalisn) in the barrier zone.

3. Application of Residual Deposits of DDT Along the Edges of the Barrier: The 1 km barrier clearing will not be wide enough to prevent all tsetse flies from immigrating into the ranch. Therefore, the barrier will be reinforced by the application of DDT to vegetation outside the perimeter of the barrier. Applications of 5% DDT will be made to the lower 3 meters of tree trunks greater than 25 cm. diameter and on the undersides of lower branches in order to kill resting flies and prevent movement of flies into the ranch area. One application will be bi monthly throughout the duration of the field experiment. The minimum insecticidal barrier will be 300 meters, and each application will probably require about 90 to 100 kilograms of active ingredient equivalent to 2.2 grams per hectare per annum (0.02 lbs) per acre annually) over the ranch as a whole, and 90 grams per hectare (0.08 lbs. per acre annually) in barrier zone. Some short-term contamination of surface water limited to the Msangazi River will occur and limited DDT may accumulate in certain nontarget organisms and in the soil. Since the area to be treated with DDT is relatively small, the effect on nontarget invertebrates, bird and mammals will be minimal.

4. Three Aerial Applications of Endosulfan: Studies of the population density of G. morsitans at the Mkwaja Ranch indicate that two or three aerial applications of endosulfan may be required in order to reduce the population to a level that can be handled with sterile males. Approximately 215 square km will be treated. The insecticide will be applied in droplets (35-45 u in diameters) that float and impinge upon resting and flying tsetse flies, but are not large enough to leave a permanent toxic residue. Endosulfan will persist at low levels in the treated areas. Each treatment will utilize 30 grams./ha. of active ingredient, totalling about 600 kg of insecticide or 90 grams per hectare each (0.0825 lb per acre total for 3 applications). Five or six such applications at two to threeweek intervals are routinely used to eradicate G. m. morsitans. Other studies indicate that even with 5 or 6 applications, residues and the effect on non-target organisms are minimal. Any such effects would normally be limited to invertebrates and fish. When high concentrations of endosulfan are used, it is toxic to fish; however, at the time of the Mkwaja ranch applications, the rivers will be dry and contamination of surface water will be of limited duration. Air polution during the actual spraying operation will be transient.

It must be noted that the normal requirement for tsetse fly eradication over an area of the same size would be five to six applications of insecticides. The use of sterile males following two to three applications will reduce the insecticide application by 40 to 50 percent.

5. Release of Sterile Male Tsetse Flies: As the summary table shows, the release of the sterile males would not affect any of the environmental factors. It should be emphasized that the flies are not radioactive, but they do have the capacity of transmitting disease as vectors of trypanosomiasis. The release of the sterile males at the rate of 3 to 6 per day per square km, following the reduction of the natural population by aerial applications of insecticide, avoids the situation in which there would be more flies than were present in the pretreatment population. The anticipated elimination of the target species from the environment should not be accompanied by an increase in population of other Glossinas species since they are habitat-specific and not interdependent.

6. Rearing of Flies and Host Animal Production: The rearing activities at the Tanga Laboratory are confined to 410 square meters of enclosed space and do not cause any environmental impact. Likewise the maintenance of the host animals takes place only on the enclosed 8 hectares and has no or little impact on the environment with the exception of waste accumulation which is dealt with by the septic tank and recycling of manure.

7. Socio-Economic Consideration: An analysis of the operational and economic feasibility of the rearing laboratory at Tanga will be possible only upon the completion of the field trials in early 1979. Similarly, a useful cost/benefit assessment of tsetse fly control could not be made on the Mkwaja ranching operation, nor could the possible application of the economic feasibility of the SIRM be definitively assessed. Only gross indicators of costs, benefits and returns were available. The Mkwaja Ranch could not operate without a careful and expensive regime of prophylactics and curative drugs or tsetse fly eradication maintained by intensive and continuous insecticide applications. Only four of the past twelve years have been profitable reflecting the substantial capital development costs, including tsetse fly control measures and an average expenditure of $3.00 per head per year for maintenance of minimal disease control. Following the analysis of the SIRM as part of an integrated tsetse fly eradication program, it will be possible to compare the Mkwaja Ranch with other ranching operations in Tanzania and with other successful livestock operations such as Ankole in Uganda and Zululand in South Africa.

The team did not have access to the detailed financial records of the privately managed Mkwaja Ranch and therefore could not directly assign observable benefits to specific operations. Nevertheless, based on observations and discussions with the ranch manager, the following indicators emerged: (1) a profitable livestock operation is not possible when the tsetse fly exists in terms of present state of knowledge of therapeutic and curative treatments: (2) tsetse fly eradication requires a large initial capital investment and continuing high cost maintenance; and (3) ranching operations in the semi-arid regions of eastern Tanzania must be well planned and well managed with respect to the carrying capacity of the land and the available water resources.

IV. APPLICABILITY OF THE ASSESSMENT

A. THE STERILE MALE INSECT METHOD (SIRM)

The elements of the Tsetse Research Project which are relevant to existing or future tsetse fly eradication projects may be summarized as follows: Tsetse fly eradication schemes require extensive planning and careful coordination of each phase of the operation. Of major significance is the fact that fly populations become undetectable well before they are actually eradicated. Due to the low reproductive capacity and the low rate of increase of natural fly populations, many generations may elapse before incipient populations are detected by normal surveillance techniques. The use of sterile males to consolidate and insure eradication in the phase following the use of other techniques may be the most effective approach under certain circumstances.

The Project's research activities involve a wide variety of specific information accrual perhaps more so than other types of control research. This is due to the fact that livestock are used to regulate at the density of natural insect populations of the same species. Thus, original data are required not only on fly production requirements, sterilization effects and handling methods, but also on a wide spectrum of population characteristics of the wild flies, e.g. density, longevity, dispersal, seasonal variation, etc. These data are necessary to make optimum use of the released insects. In addition, integration of the sterile insects with conventional methods will provide new perspectives on population dynamics that can be useful in other programs. Thus, all aspects of the biology, ecology, and insecticide research will provide data and concepts that are directly relevant to other tsetse fly eradication projects.

Population studies being conducted will be particularly important as will studies on the effectiveness of insecticidal barriers used to supplement natural or artificially created barriers. These significant facets of control technology will have a major bearing on most other eradication projects. The advances made on rearing and sterilization research will directly expand the capabilities of African scientists to conduct tsetse fly research and related studies on disease transmission. Field studies with laboratory reared flies will greatly enhance the ecological and biological information currently available.

Conclusive proof that the sterile male technique is effective will make available another tsetse fly eradication technique for futher practical development. Mass rearing of other species of tsetse flies as developed for G. m. moristans at the rearing laboratory, will be applicable to other species, as well as related studies on artifical rearing techniques being supported by Project funding. An increased capability in rearing other species will increase the flexibility of the technique by making its use advantageous in areas with more than one important vector species. The integration of the sterile male releases with control programs that might otherwise be only partially effective may result in effective and efficient eradication of target species that would not have been attempted. The costs of using the sterile male technique in this research program may provide useful information for predicting the costs for integrated eradication schemes in other suitable areas. Thus, any contemplated new eradication scheme should consider incorporation of sterility techniques in the planning stages because of the potential economic savings and/or increases in the total area of land cleared with a fixed amount of capital. For example, in addition to existing tsetse fly control projects, consideration is being given to field operational programs at four locations in Tanzania. 1. The island of Zanzibar; 2. The West Lake area; 3. Mafia Island east of Dar es Salaam; 4. the Handini

area near Masailand. Assuming successful completion of the SIRM trails, it may be anticipated that the insectaries at Tanga might be expanded to provide sterile flies for new programs. Relevant to this point, in 1971, a panel of 32 internationally recognized experts met in Paris to deal with the possible applications of the sterility principle for tsetse fly control. The panel analyzed the possible advantages and disadvantages, and their summary remains the most reliable assessment yet available. The following remarks are based upon the report of the panel, (IAEA Report, 1972).

1. Advantages of the Sterile Male Insect Method: The principal advantage of the SIRM is that the control effort becomes more economical as the natural population declines. This economy results because increasing ratio of sterile to wild males are achieved. As the program proceeds, the total numbers of release flies can be reduced and control becomes increasingly more efficient. In contrast, conventional multiple application of insecticides becomes less efficient in terms of the number of insects killed as the population declines because the cost and percentage kill factor per application remains fixed.

In areas where the SIRM can be utilized alone, this technique avoids contamination of the environment and selectively attacks one Glossina species, resulting in a minimum distriburbance of the environment and other insects. Even if an integrated use of insecticide is indispensable, the contamination of the environment nevertheless is considerably less than that which results from a program based entirely on chemical control. Unlike the majority of other Diptera, Glossina species have an extremely low reproductive potential and low rate of increase per generation. Therefore fewer sterile males are required. The density of the vegetation in the environment, often a serious obstacle for the application of insecticides, does not hinder the dispersion of the sterile insects.

When population density is low the efficiency of eradicating the species is theoretically better with sterile insect release method than with insecticides. The sterility method could be utilized as the final phase of an integrated program. Release of sterile males in low numbers can prevent reestablishment of the species. This technique may be cheaper and more effective than maintaining constant surveillance. In areas, where two Glossina species coexist, the elimination of one species by the SIRM is not expected to result in a sudden increase in numbers of the second species since population sizes are not believed to be interdependent.

Where the control of tsetse is regarded by the authorities as necessary to game reserves or national parks, the use of the SIRM would minimize the detrimental side effects of control. Reduction of the wild tsetse population by other methods may be necessary before sterile males can be effectively used. The use of not more than two or three

applications of a nonpersistent insecticide is not likely to significantly contaminate the environment or damage the fauna except where rare endemic insects are present. Even in areas where the SIRM does not represent an economical gain over other tsetse suppression techniques, it may be the method of choice where disadvantages of chemical or other control methods must be avoided.

2. Disadvantages of the SIRM: The method is not practical nor is it designed to be used alone against high natural populations. Prior reduction with chemicals or other means is a prerequisite. When used alone this method, unlike insecticides, does not immediately reduce the insect population enough to rapidly interrupt disease transmission. Release of large numbers of sterile flies in an area where trypanosomiasis is endemic could temporarily increase the transmission rate. For this reason, the method should not be used alone in areas where human trypanosomiasis is endemic and where immediate interruption of transmission is required.

B. SEPARATE AND INTEGRATED APPROACHES TO TSETSE FLY ERADICATION

Before chemical insecticides were developed, the two most commonly practiced methods for controlling tsetse flies involved clearing woody vegetation on which the flies depend for shelter and eradicating game animals on which they depend for food. These methods are rarely practiced at present; but because of the need to clear a barrier around the Mkwaja Ranch, the method of vegetation clearing is included in the following description of tsetse fly eradication techniques.

1. Clearing of Vegetation. Sheer clearing, involving the destruction of all trees and shrubs, is an effective means of eradicating Glossina. It is costly, even when carried out by mechanical methods (Glover et al, 1959; Wooff, 1967) and is now rarely employed except to establish barriers, often in conjunction with insecticides, to prevent the reinvasion of areas freed of tsetse flies. The technique has been employed over wide areas of country against species of the morsitans group and linearly against riverine and lacustrine species of the palpalis group. In some circumstances soil erosion can result, but there is much evidence that in sanannah regions, removal of all trees and shrubs often causes grass growth to increase and to improve pasture (Ford, Nash and Welch, in Mulligan, 1970). Discriminative or partial clearing involves the removal of only those elements of vegetation essential for the survival of Glossina. It has been extensively practiced against riverine G. palpalis and G. tachinoides in West Africa (Nash 1969) and G. morsitans, G. swynnertoni and G. pallidipes in East Africa.

21. Game Destricution. Slaughter of game animales as a method of tsetse control has been widely practiced in the past in Uganda and Rhodesia. Even when refined by removing only the favored host species (Corkbill et al, 1969), the method is unacceptable today.

3. Insecticides. Treatment of tsetse-infested zones with insecticides is currently the most common method of eradication. Insecticides are applied as persistent deposits of such compounds as DDT, dieldrin, or endosulfan (either from the ground or from helicopters), or as sequential applications of formulation of either dieldrin or endosulfan of ultra low volume from fixed - winged aircraft.

4. Toxicology. The Acute Oral/Dermal (LD^{50} in Rats) and the Acute 24 hour (LC^{50} in Fish) of 4 Pesticide/Herbicides is given below in Mg./Kgm.

	Endosulfan	DDT	Dieldrin	2/4- D
Oral	43	113	46	375
Dermal	130	2000	90	-
Fish*	2.7	7	14	100

*P.P.M. for Blue Gills/Trout fingerlings.

Heavy deposits of persistent pesticides can be applied discriminatively from the ground as a single treatment to the resting sites of the fly. These persistent deposits remain effective for several months, and therefore a single application even kills the flies which emerge from puparia in the soil during the weeks following the application. This method is particularly applicable against species of Glossina with linear distributions and has been widely practiced against G. fuscipes in East Africa (Glover et al, 1960). The method is less practicable against those species, such as G. morsitans, which often occur throughout wide tracts of country. Such species can be attacked, however, when their distribution is restricted during periods of climatic stress (Davies 1971). The most commonly employed insecticides in ground-spray campaigns have been DDT and dieldrin.

Presistent deposits can also be applied by helicopter. Applications can be restricted to certain habitats but are less discriminative within those habitats than are applications from the ground. Extensive successful operations, primarily against G. morsitans, have been performed in Nigeria. Dieldrin emulsion has been the most widely used insecticide, but trials have also been conducted with endosulfan (Spielberger and Abduratim, 1972; Spielberger et al, personal communication).

Observation made on the side effects of insecticides used in various tsetse control schemes indicate that applications of persistent deposits leave heavy local residues (Park et al, 1972, cites initial deposit of 1-10 g active ingredient m^2) that also affect other organisms, especially when applied over large areas. Koeman and his colleagues have studied

these side effects for many years. Koeman and Takken (1976) showed that even a single application of residual dieldrin or endosulfan caused mortality in many nontarget species. Helicopter application affected a wider range of bird species than discriminative groundspray application. Certain species of the fringing forest birds are very vulnerable and disappeared from the treated area. Certain mammal populations also markedly decreased in size (examples are Tantalus monkeys after application of dieldrin, and fruit bats after aerial residual application of endosulfan). Appreciable mortality occurred among fish, amphibians, lizards and snakes.

In general, groundsprays are more discriminative and are therefore less likely to cause irreversible damage than are helicopter applications. Endosulfan was found to cause more damage to cold blooded vertebrates than dieldrin; warm blooded species reacted conversely. In areas treated once, many of the affected species repopulated the treated areas a year or so later by migrating from the nearest untreated populated habitat, provided the areas reclaimed from tsetse had not been altered drastically and the habitat remained suitable. Residues of dieldrin and DDT observed in fish, fish-eating birds, and other organisms collected in areas sprayed one or two years previously have generally been low (unpublished WHO/FAO Report 1976).

When the distribution of the fly is diffuse, restricted application is not feasible and a blanket cover is required. Since residual deposits need to be relatively heavy in order to obtain adequate persistence, it is not feasible to apply insecticide on this scale over the whole habitat available to the fly. The development of methods for the sequential application of nonresidual ultra low volume formulations of dieldrin and endosulfan has been reviewed by Lee (1969) and Burnett (in Mulligan, 1970). Concentrated solutions of insecticide in volatile oil are used, which are dispersed as medium aerosols consisting mostly of 20 - 50u drops. The insecticide must be highly toxic to the fly so that a single drop will contain a lethal dose. Park et al (1972) used 30 gm of active ingrendient (a.i.) per hectare in each of five applications of endosulfan to eradicate G. morsitans in Zambia, and in Botswana as little as 6gm a.i./ha have been used per application (Kendrick and Alsop, 1974). Because puparia in the soil cannot be reached by the insecticide, repeated applications (usually 5 or 6 at about 18 day intervals) are necessary to prevent newly emerged females from reproducing.

A team from the Centre for Overseas Pest Research, London, is currently investigating the effects of sequential aerial application of endosulfan on nontarget organisms in Botswana. In contrast to the effects of residual aerial applications, preliminary results with sequential application suggest that there are unlikely to be any immediate lethal effects on fish or terrestrial or fresh water invertebrates (Russell-Smith, personal communication) because Glossina are highly susceptible and require much less insecticide than other insect species. Most studies followed application rates of 6 gm a.i./ha but there were also little evidence of direct mortality after one application at 12 gm a.i./ha; endosulfan can be highly toxic to fish, but at least these extremely low application rates it clearly had no detrimental effect. No data are yet available for possible sub-lethal effects of endosulfan; samples of fish and water are currently being examined for insecticide residues.

4. Genetic Control. In addition to the SIRM, various other genetic control techniques have been proposed. The most practical at the moment seems to be the exploitation of the hybrid sterility resulting from some combination of crosses between subspecies of G. morsitans. No field trials have been carried out.

5. Biological Control. A number of attempts (especially by Nash, 1933) have been made to exploit parasites of tsetse as a means of control. None have been successful. Tsetse predators and pathogens must be categorized and then effects on tsetse populations must be quantified before they can be used as control agents. Research is proceeding on other chemical control techniques. At a number of laboratories in the United States and Europe, research projects are underway to characterize the effects of juvenile hormones (Denlinger, 1975) ecdysones (Whitehead, 1976) and diuretic hormones (Gee, 1975), but the formulation of a hormonal insecticide for use against Glossina is only a distant prospect. Such insecticides are already in use against other pest species, they have a number of attractive features, including virtually no harmful effects on mammals.

The recent development of highly efficient catching devices that utilize the natural attractiveness of host animals (Vale 1974) is a major advance. In addition, a sex pheromone in G. m. morsitans has recently been isolated and identified (Langley, Pimley, and Carlson 1975), suggesting the possibility of developing a male attractant for use in control activities. It has been suggested that the sounds produced by tsetse flies may act as a means of communication (Kolbe, 1973). Should this be so, it may be possible to devise an auditory attractant.

C. BENEFITS AND IMPLICATIONS FOR DEVELOPMENT STRATEGIES

The tsetse fly belt stretches across the middle of Africa. Generally, it lies between latitude 12 degrees north and 20 degrees south. Little of this vast area is utilized except for periodic livestock grazing, much of which is nomadic. It has been estimated that 240 to 325 million hectares are presently utilized for livestock grazing and that another 200 million hectares could be developed. Recent advances in soil sciences and soil moisture management could expand these estimates. Therefore, this tsetse fly belt looms importantly in the goal of increasing the food production of Africa — and, in fact, of the world. Yet, while the area is potentially productive, its development is complicated by many problems: poor soils, inadequate water, disease, and perhaps in some cases maladaptive social features of the human populations may at times be comparable to the tsetse fly in their negative effects. Moreover, campaigns to control animal trypanosomiasis cannot be isolated from the efforts to prevent other animal diseases. East coast fever, rinderpest, and contagious bovine pleuropneumonia are a few of the many diseases endemic in the tsetse fly belt of Africa.

The mapping of soils by classes and capacity for supporting agriculture or livestock production have been limited in Africa. Techniques are being refined which can help, although progress will depend upon building indigenous capabilities for soil classification and analysis in each nation. Soil classification is necessary since any development strategy for land utilization must reflect the use potential and carrying capacity of the land. The details of land use planning in each country naturally depend on pre-existing institutions and policies. Each form of ranch system must be made economically viable and consistent with national goals on size, employment, and production. Beyond the development of the farmland itself, improvements in roads, markets processing and storage, worker incentives and education and training opportunities are all integral parts of any successful program of economic and social change. The tsetse fly is thus a major constraint, but its eradication is only the first step toward making the tsetse fly belt of Africa productive. Since animal trypanosomiasis is only one of many constraints on optimal livestock productivity, the full benefits of tsetse fly eradication can only be attained within a system in which all other constraints have been eliminated or are at least brought within manageable limits.

Although development planners and tsetse fly experts have stressed that tsetse fly eradication must be integrated with rural development and land use, complete success has seldom been achieved. The Mkwaja Ranch provides an opportunity to experiment with new tsetse fly eradication techniques which appear to be less hazardous to the environment. The ranch also offers the opportunity to observe the integration of tsetse fly control techniques with livestock and resource management. However, the production outputs of the Mkwaja ranch currently are less than satisfactory. Factors other than the tsetse fly which bear on the productivity of the ranch are the relatively low levels of forage production and its seasonal variation in nutritional value: rapid regeneration of bush; other animal diseases; and a calf breeding rate that is limited to about 50 percent per year. The death loss due to trypanosomiasis is low but the effective chemotherapeutic regime requires a substantial investment. Even in this relatively well managed case, the data show that commercial ranching in the semi-arid coastal region of Tanzania is still at best marginally profitable. These observations reinforce the need to precede major tsetse fly eradication eforts with investigations on land carrying capacity, water availability, and training and incentive programs for the populations who will occupy the land claimed from the fly.

If tsetse fly eradication is undertaken on a large operational scale, appreciable environmental modifications will occur and must be weighed against the benefits, short term and long term, of increased food production and employment. It is inevitable that man and his domestic animal will replace wildlife on many areas and that the large game animals will be reduced in number. These anticipated modifications in the environment must be studied well in advance of any large scale tsetse fly eradication programs.

Throughout the twenthieth century, Africa has been exposed to numerous grazing and development schemes, many initiated during the colonial period. Much effort and capital have been spent to superimpose western technologies of animal husbandry and range management on pastoral subsistence economies. Those attempts have often failed because they were not combined with a parallel effort to improve the socio-economic environment of the local people. These past failures dramatize the importance of involving the local communities in the initial stages of development programs. Proposed changes must be carefully evaluated from the perspective of the local populations, and must be supported by thorough analyses of human needs and capabilities. In analyzing the effectiveness of the water development and grazing schemes in Masai areas, Z. Neveh (1966) has found that the failure of the programs could not be explained by the "insatiable desire of the Masai to build up livestock populations for bridal wealth and prestige" as developmental planners have often argued. Rather, the earlier disruption of the Masai nomadic ecosystems by the encroachment of agriculturists upon the better lands formerly available to them caused the Masai to depend for their survival on larger and larger herds. The trauma of the often repeated

experience of disaster and starvation... and the development of water points and disease controls have not improved things but made them worse.

In a similar study of African Pastoralists, Alan H. Jacobs (1965) has described how preconceived views and prejudices about a pastoral society can impair the development planner. For example, "The generalization that pastoralism implies an especially strong and characteristic resistance to social change deserves attention... . The evidence for such a statement is by no means consistent or conclusive. Not only have many African pastoral societies been dependent on external markets and responsible to social change over long periods of time, such as the Fulani and Somali, but others have changed rapidly within a period of a few years, such as Kipsikis and Nandi of Kenya."

Such studies on man and his environment in Africa should be taken into account by every development project, although clearly they were beyond the resources of this environmental assessment.

The Assessment Team did not attempt to identify the options available to national planners in Africa, nor to assess the tsetse fly eradication experiences in Tanzania. The Team wishes to emphasize, however, that international agencies involved in tsetse fly eradication schemes must act in close accord with the host countries. The role of foreign experts should be primarily to determine the probable affect of the various eradication options, and the range of uncertainties regarding the consequences. International and national aid agencies then must leave to the host country in light of its own political and development strategies, the interpretation of this advice and the decision as to what the country should actually do. In particular, the participation of African nations in a continent-wide effort to eradicate the tsetse fly, such as the FAO program, will in the end be weighed against each nation's priorities.

V. CONCLUSIONS

The team concludes that the Tsetse Research Project in Tanzania will have negligible detrimental impact on the environment of the Mkwaj Ranch. In those localized situations where some environmental change h been anticipated, the effects have been evaluated. The objective of th Research Project is to test a new technique for the control G. m. morsitans in an area where it will have no effect on the present use an occupation of the land. To this extent, the 435 sq. km of the Mkwaja Ranch is atypical of the 10 m. square km of tsetse fly infested Africa The test site was selected to fulfill the conditions and requirements o the experiment.

An assessment was made of the socio-economic impact of the research project upon the ranch environment and the rearing laboratory environment in Tanga. Other than the important component of training and the demonstration of the role of science in helping man shape his environment to his needs, the social impact of this project has been minimal.

The creation by the ranch management of a 1 km wide barrier clearing around the test site to reduce fly immigration is being completed with project funding. The replacement of the natural habitat with grassland in the barrier zone will have a high level of impact on the plant and animal communities, but the disturbance on the ecosystem will be localized and the proper maintenance of grasslands may contribute to a stable ecosystem, providing additional forage.

The herbicide, tordon 155, will be applied to the tree stumps in the barrier zone. Since the applications will be restricted and will be applied manually with brushes, the minimal effects will occur only in the barrier zone.

In order to reinforce the barrier and protect the test area from any fly immigration, DDT will be applied bimonthly to a 300 m strip along the perimeter of the barrier. This selective application will deposit about 545 kilograms of DDT on the test site. This represents an application level of 280 grams/hectare (0.25 lbs/acre) for the treated area. The localized effects of the DDT treatments on the soils and atmosphere will be minimal but the effect on the ecosystem will be high. However, the effects are limited to less than 8 percent of the total test area and within this area only 3 to 10 percent will be actually sprayed.

Two or three aerial applications of endosulfan will be applied to reduce the tsetse fly population prior to the release of sterile males. The total amount of insecticide will be about 1800 kg (92 grams per hectare of 0.0825 lb/acre). These applications will leave minimal residues which will not measurably affect nontarget organisms.

The daily release of 3 to 6 sterile male flies per square kilometer will not affect the environment. The flies are not radioactive and the number released will be lower than the initial population and therefore, the incidence of animal trypanosomiasis will not increase.

V. GUIDELINES FOR FUTURE ASSESSMENTS

The assessment team recommends that when an initial examination of a proposed AID action identifies the need for an environmental assessment, it should be combined with the development of the work plan. This procedure will substantially reduce the costs and enable AID to consult with experts during the preliminary planning stage.

The team recommends that the AID program authorities identify the individuals required for an assessment. A tsetse fly project should include the following specialists:

1. a chairperson, preferably a tsetse fly expert;
2. an entomologist, whose work compliments the chairperson; and
3. an ecologist or wildlife biologist.

Depending upon the design of the project, the environment in which it is to be undertaken, and requirements for integration of land use and development programs, the following specialists should be included as team members or as experts to be consulted by the chairman.

4. animal production specialist; and/or epidemiologist (sleeping sickness); and
5. behavioral scientist.

The ex-officio members of the team will include the mission project officer and the Washington AID program manager. The organizational arrangements and correspondence should be the reponsibility of the Washington office of the AID program manager.

The host country representatives participating in the preliminary planning of the proposed action should be invited to recommend the host country specialist in tsetse fly control and a planning officer from the relevant ministry as members of the assessment team.

Before visiting the site of the proposed action, the members of the assessment team should convene for several days in Washington. At that time, AID should provide all members with relevant past assessments, project evaluations, reports on ongoing projects in related fields, all preliminary data on the proposed action, and any general information on tsetse fly eradication programs.

The chairperson should assign specific responsibilities to each team member. Arrangements must be made in advance for the team to consult with the appropriate experts and officials in the host country during the period of the site visit.

The site visit should be of a duration to allow the necessary data to be collected--one to two weeks. At the conclusion of the site visit, each team member should submit his report to colleagues and as a team prepare the draft report. The team noted that "when AID unilaterally considers that there is a reasonable risk of significant adverse effects on the environment from an activity proposed to it for support, and when efforts to encourage the incorporation of appropriate safeguards are unsuccessful, AID reserves the prerrogative of declining to participate in the activity."

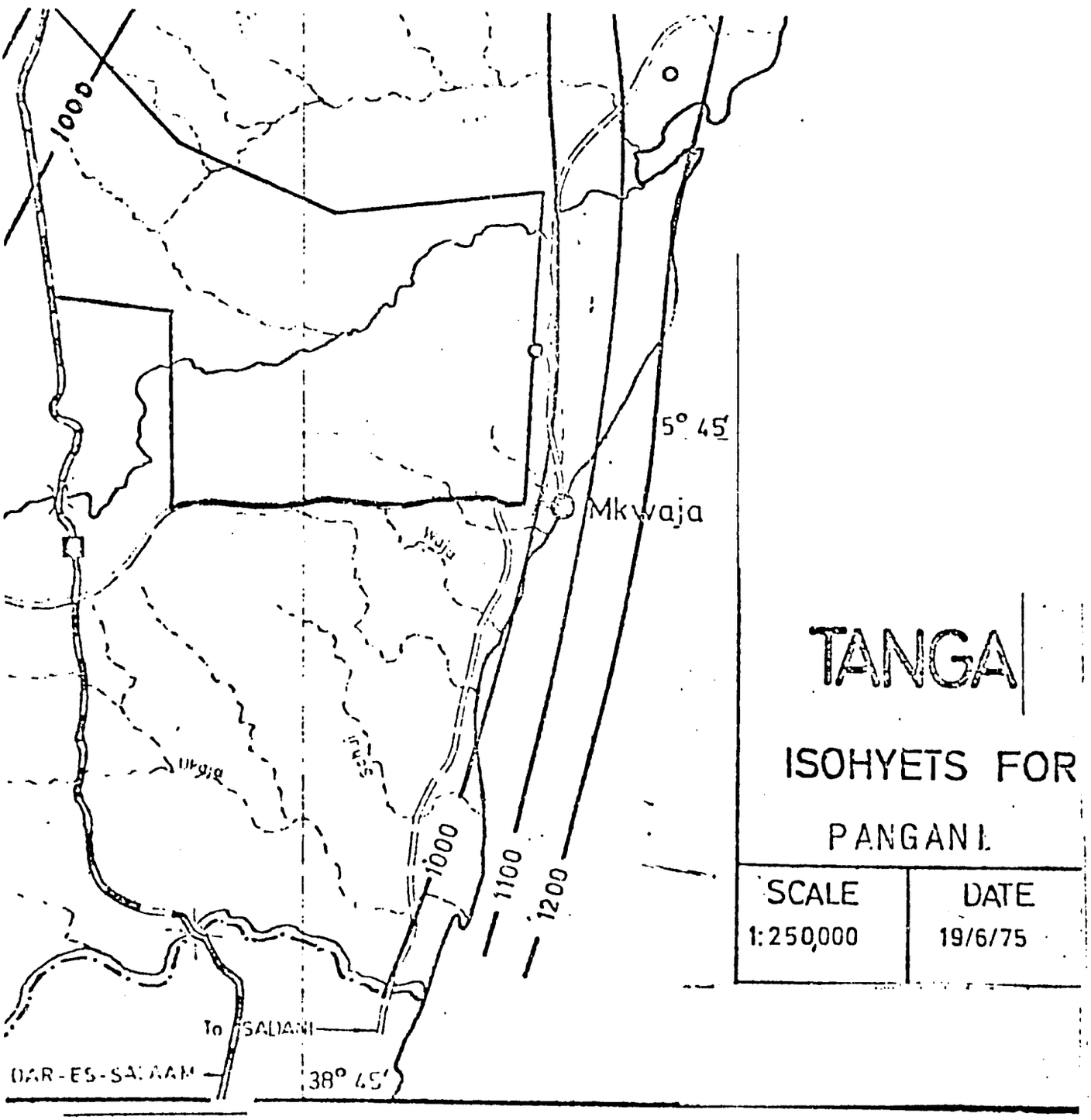
The team has noted that international agencies, FAO and WHO, have undertaken continent-wide assessment of long range programs for tsetse fly eradication in Africa, including a two-year study which will survey selected regions for an assessment of the socio-economic importance of trypanosomiasis and costs of alternative methods of control. The U.S. Government is a participant in the specialized agencies and therefore the team does not see any need for AID to undertake the broad program assessments described in section 216.6 of the Rules and Regulations. Attached to this report are the FAO/WHO studies to date.

APPENDIX A

Figure 1.--Average monthly precipitation over 21 years shows considerable departure from normal during the past 8 years, especially in the short rain season.

APPENDIX 3

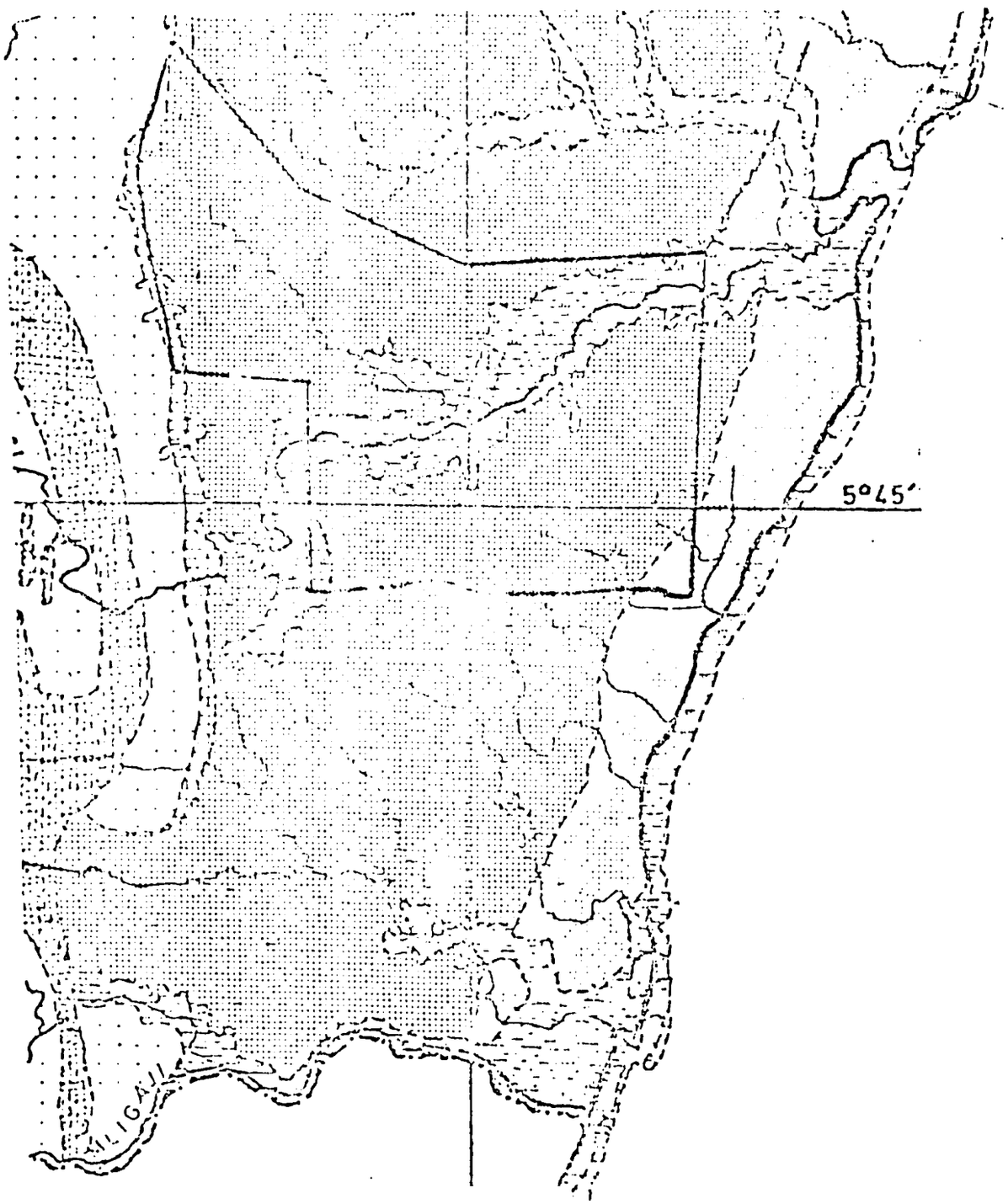
Map 1. -- Isohyets for average precipitation, Mkwaja Ranch. 1/



1/ Preliminary maps provided by Ministry of Water Development and Power, and German Agency for Technical Cooperation, Ltd., 1975.

APPENDIX A

Map 2. -- Generalized geological map, Mkwaja Ranch. [1]



[1] Preliminary maps provided by Ministry of Water Development and Power, and German Agency for Technical Cooperation, Ltd., 1975, (see overleaf).

ap 2. -- Continued

NEOGENE

	Na	River alluvium, tidal swamps, beach sands, mbuga soils
	Nu	Undifferentiated soils on Usagaran rocks
	Npl-r	Orange-red soils, raised pleistocene reef, loosely consolidated sands of the coastal plain

JURASSIC

	Jm-u	Septarian mudstones and marls with massive to poorly bedded siltstones, patch reef limestones
	Jm	Tanga limestone: massive to poorly bedded limestones, reef limestones oolites

USAGARAN

	Xg	Gneisses, granulites, amphibolites of various composition and origin
	Xc	Crystalline limestones marbles
	Xp	Peridotites and other basic meta-intrusives

Fault

Probable faults

APPENDIX B

Table 1. -- Large Mammals, Birds, and Reptiles on the Mkwaja Ranch.

LARGE MAMMALS

Ungulates

Buffalo, Cape *
Syncerus caffer

Bushbuck
Tragelaphus scriptus

Bush-pig *
Potamocherus porcus

Dik-Dik, Kirk's *
Rhynchotragus kirki

Duiker, Red
Cephalophus natalus

Duiker, Blue *
Cephalophus monicola

Elephant, African *
Loxodonta africana

Giraffe, Masai *
Giraffa camelopardalis tippelskirichi

Heartbeast, Coke's *
Alcelaphus buselaphus cokei

Hippopotamus
Hippopotamus amphibius

Kudu, Greater
Tragelaphus strepsiceros

Reedbuck, Bohor
Redunca redunca

Sable Antelope *
Hippotragus niger

Waterbuck
Kobus ellipsiprmnus

Wart Hog
Phacochoerus aethiopicus

Predators

Serval *
Leptailurus serval

Civit, African *
Civettictis civetta

Genet *
Genetta sp.

Hyena, Spotted *
Crocuta crocuta

Leopard *
Panthera pardus

Lion *
Panthera leo

Wild Dog, Cape hunting *
Lycaon pictus

Other Mammals

Ant Bear *
Orycteropus afer

Baboon
Papio anubis

Bat, Fruit & others
Pteropidae

Bush Baby *
Galagos sp.

Hare, Crawshay's
Leporidae

Monkey, Colobus *
Colobus polykomos

APPENDIX -

Table 1 (continued)

Other Mammals

Monkey, Vervet
Cercopithecus aethiops pygerythrus

Monkey, Green (Blue)
Cercopithecus aethiops sabaeus

Pangolin, Giant *
Manis gigantea

Rat, Cane *
Thryonomys swinderianus

Rat, Norway
Rattus norvegicus

Shrew, Elephant *
Elephantulus rufescens

BIRDS

Bustard, Lesser *
Ardeotis kori

Crow, Pied
Corvus albus

Cormorant, Longtailed
Phalacrocorax africana

Eagle, African Fish
Cuncuma vocifer

Eagle, Bateheur *
Terathopius ecaudatus

Eagle, Crowned Hawk *
Stephanoaetus coronatus

Eagle, Long-crested Hawk
Lopoaetus occipitalis

Eagle, Tawney
Aquila rapax

Eagle, Sea (Osprey) *
Pandion haliaetus

Egret, Cattle
Bubulcus ibis

Francolin, Coqui
Francolinus coqui

Guinea Fowl, Crested
Guttera pucherani

Hammerkop
Scopus umberta

Heron, Goliath *
Ardea goliath

Heron, Grey
Ardea cinerea

Hornbill, Ground & others
Bucorvus leadbeateri

Ibis, Hadada
Hagedashia hagedash

Kestrel, Greater
Falco rupicoloides

Kite, African Black
Milvus migrans

Stork, Open-bill *
Anastomus lamelligerus

Stork, White *
Ciconia ciconia

Stork, Maribou
Leptoptilos crumeniferus

Stork, Saddlebill
Ephippiorhynchus senegalensis

APPENDIX 3

Table 1 (continued)

Stork, Spoonbill
Platalea alba

AMPHIBIANS AND REPTILES

Crocodile *
Crocodylus niloticus

Frog
Rana sp.

Lizard, Monitor
Varanus niloticus

Snake, Boomslang *
Dispholidus typhus

Snake, Banded Cobra
Naja haji

Snake, Mocambique Spitting Cobra *
Naja mossambica

Snake, Green Momba *
Dendroaspis augusticeps

Snake, Black Momba *
Dendroaspis polylepis

Snake, Puff Adder *
Bitis arietans

Snake, Rock Python *
Python sebae

Toad
Bufo sp.

* Asterisk following a species indicates the animal occurs or is seasonally present on the test site but was not observed during the field inventory.

Table 1 cont. Roadside game census and estimated biomass along 373 km of bush track on the Mkwaja Ranch, Republic of Tanzania.

Species	Number	Estimated Biomass 1/ (lbs/ac)	(kg/ha)
MAMMALS			
Baboon 2/	28	0.28	0.31
Bushbuck	4	.15	.17
Duiker, Redback	1	.006	.007
Hare, Crawshay's	1	.0006	.0007
Hippopotamus	21	15.0	17.0
Kudu, Greater	25	2.4	2.7
Monkey, Vervet	49	.22	.25
Monkey, Blue	1	.002	.002
Wart hog	109	2.1	2.4
Waterbuck	45	3.3	3.7
Subtotal		23.5	26.5
BIRDS			
Cormorant, Longtailed	3	0.003	0.003
Eagle, Tawney	2	.002	.002
Eagle, African Fish	2	.003	.003
Egret, Cattle	158	.076	.09
Francolin	5	.001	.001
Guinea Fowl, Crested	104	.1	.1
Hammerkop	2	.001	.001
Heron, Grey	2	.004	.004
Hornbill, Ground	1	.002	.002
Ibis, Hadada	7	.001	.001
Kestrel	1	.00001	.00001
Kite, African	5	.001	.001
Stork, Maribou	5	.03	.03
Stork, Saddlebill	6	.02	.02
Stork, Spoonbill	2	.005	.006
Vulture, Whiteback	2	.003	.003
Vulture, unclassified	34	.04	.04
Subtotal		0.297	0.307
REPTILES			
Lizard, Monitor	1	.002	.002
Snake, Banded Cobra	1	.0002	.0002
		0.0022	.0022
Total		23.8	26.8

1/ Assumption: the mean visibility of 25 km on either side of roads and tracks traversed was used to establish the area base for biomass computations; body weights were estimated using available data (Ledger, 1963, 1964, 1968).

APPENDIX C

Literature Review of Plant Communities

World Ecosystems have been variously identified and are continually being refined. One appropriate international treatment put forth by Ellenberg and Mueller-Dombois (1967) and slightly modified by UNESCO (1969, 1973) has recently been suggested by Reichle (1970). Their accompanying map show this East African coastal belt in the "Tropical Ecosystem Complex" which falls into 6 classes; the one under study being the "Savannah, Scrub-woodland Complex."

In a general classification scheme for world vegetation, Fosberg (1961) working with the International Biological Program (Peterken 1967, IBP Handbook 4) has suggested this test site falls into a Formation Class of closed vegetation in tall Savannah graminoids of more than 1 meter with a closed canopy. Further, his description identifies the evergreen (tree) savannah into an evergreen broad sclerophyll savannah of megophyllous evergreen sclerophyll of the type found in various palm savannahs in Africa and Tropical America.

Broadly speaking, White's vegetation map of Africa (Greenway 1973) shows this assessment area to be completely within the East African Lowland Evergreen Bushland type. It is bounded on the west by both the 1) Broad Leafed Wooded Grassland and the 2) Thorn (Acacia) Wooded Grassland and Semi-desert vegetation of the inland plain. According to Greenway, the test site area is technically classified as Wooded Grasslands (main type) of the Palm Stand Grassland subtype (Interzonal subtype) and the vegetation patterns fall neatly into his <u>Coastal Evergreen Bushland</u> community. His description continued:

"A conspicuous feature of this vegetation is the palms of the genera Borassus and Hyphaene, both may be wide-spread or the latter in small groups which are widely scattered through the grassland.

The palms may only be Borassus or Hyphaene, sometimes both together. If other trees, usually evergreens, occur in island clumps with the palms, the vegetation would then be classed as Coastal Evergreen Bushlands."

Pratt et al. (1966) have produced a classification scheme and accompanying maps in a discussion of East African rangeland that shows the assessment area to be in a coastal belt of "Wooded Grassland and/or Bushed Grassland." Their work on area classification also places the Mkwaja site in Ecological zone III of Moist Bush and Woodland, characterized by a dry subhumid to semi-arid climate. In terms of agriculture potential, it is not suitable as forest but has high potential for intensive agriculture where soils and topography permit. Range grazing use is best on an extensive system but where management can be intensified, stock carrying capacity is high. They suggested upwards of 5 ac (2 ha) per beast per year or higher. They recommended, "Regular burning may be necessary for high range production, particularly where tall Hyparrhenia dominates the grassland."

Only one known ecological land use survey dealing with grazing potential is known to exist for this portion of the Tanga Province (Van Voorthiuzen 1970). However, a detailed study of similar coastal ecosystems beginning in the Kwale region, 200 km north of the ranch, provides interesting parallels in land use (Moomaw 1960). Although much

variation occurs along the East African coastline, environmental conditions comparable to those found on the test site occur as far north as the Tana River in Kenya (Dale 1939, Heady 1960, Atlas of Kenya 1970, Atlas of Tanganyika 1956).

Working in Tanzania, Gillman (1949) provided a vegetation classification scheme which merits reconsideration. Both he and Greenway (1973) have suggested the threshold between Wooded or Bushed Grassland and Thicket (bushland or scrubland) to be 50% aerial overstory coverage. Considering the effects of overstory cover depression on understory herbage production, forage availability, and other features of land use such as rangeland reclaimation by fire or mechanical means, the 50% cover-class threshold seems very acceptable. Both these researchers have also proposed a 10% cover threshold figure from the grassland to woodland type. Other workers have suggested variable amounts of crown cover as the breaking point between classes of woody vegetation (Fosberg 1967, Gwynne 1976, Greenway 1943, Moomaw 1960, Pratt et al. 1966).

The second aspect of local classification is based on physiognomy: trees, shrub or bush height and number of stems (single or multiple) separates woodland from bushland. These features are generally agreed among scientists working in East and Central Africa, i.e., single stemmed trees or shrubs over 5 m are considered in forest or woodland types whereas multi-stemmed shrubs or low trees less than 5 m are considered bush. The conventional distinction between forest and woodland is whether or not the tree crowns are in contact with one another.

In conclusion, based upon a review of plant classification schemes and Tsetse fly habital requirements, the following method was used in preparation of the base map for the assessment area (Table 1).

APPENDIX C

Table 1. -- KEY TO PHYSIOGNOMIC COVER TYPES - MKWAJA RANCH

Forest = Trees or single stemmed shrubs greater than 5 m tall with 100% crown cover

Woodland = Trees or single stemmed shrubs greater than 5 m tall with less than 100% crown cover, i.e., not touching 1/

Bushland)
Thicket) = multi-stemmed shrubs less than 5 m tall with greater
Scrub) than 50% crown cover

Wooded Grassland = trees or single stemmed shrubs greater than 5 m tall having crown coverage between 10% - 50%

Bushed Grassland = multi-stemmed shrubs less than 5 m tall having crown coverage between 10% - 50%

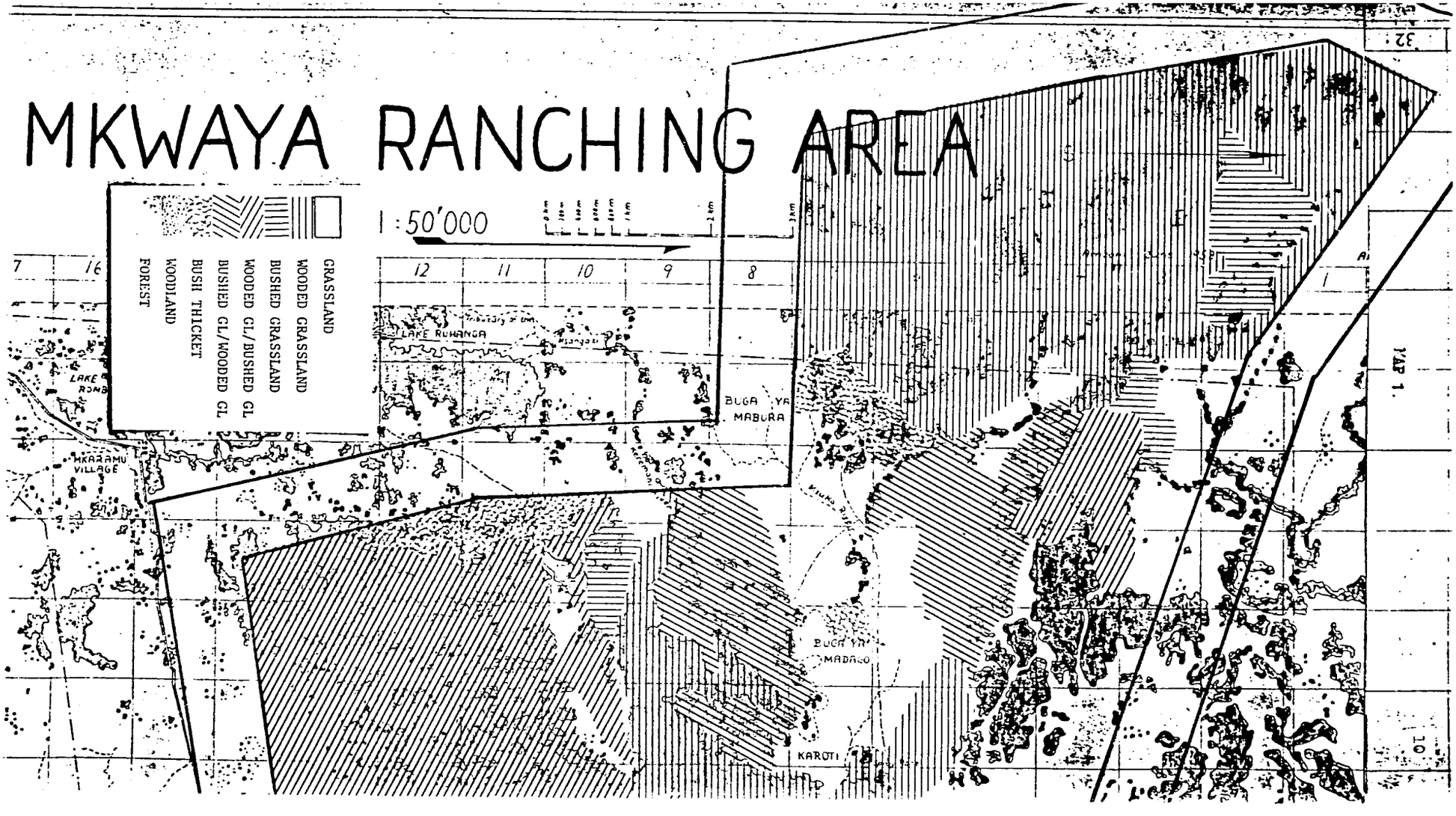
Grasslands = areas dominated by graminoids having less than 10% shrub or tree crown cover

Complexes: Wooded grassland and Bushed grassland may occur in combination but coverage may not exceed 50%

1/ Grouped-tree grasslands (forest islands) may be interspersed with any of the classifications above.

Map 1. -- Cover types of the Mkwaja Ranch as they relate to rangeland potential and Tsetse fly habitat, (overleaf).

MKWAYA RANCHING AREA



APPENDIX 3

Plant Communities and Cover Types

The dominant vegetation feature of the eastern quarter of the ranch is a Doum Palm-high grass "savannah." Scattered Doum Palm trees with a Hyparrhenia tall-grass understory predominates throughout. In this predominatly grassland association, regeneration of young palms has been a management problem. Also, to the south and east, Acacia zanzibarica has invaded in sufficient density to class some areas in the mixed Wooded Grassland type. A false Acacia, Dichrostachys cinerea, and cat claw, Harrisonia abyssinica, have also become troublesome invaders here. Important high grasses are Hyparrhenia dissoluta, H. filipendula, H. rufa, and Andropogon schirensis. Heavy grazing converts this composition to mid-grasses, such as, Digitaria scelarum, Bothrichloa glabra, Dactyloctenium aegyptium, Eragrostis superba, and Cynodon dactylon. Common trees besides Doum Palm that constitute the overstory of this Wooded Grassland, and spotted throughout other major Grasslands as well, are Sclerocarya caffra, Tamarindus indica, Terminalia spinosa, Kigelia aethiopum, Balanites sp., and Boscia sp.

The mixed Wooded Grasslands/Bushed Grasslands of the central uplands are the dominant communities between the grouped tree forest islands. Common trees are the conspicuous Baobab, Adansonia digitata and Euphorbia candelabrum, the everpresent Doum Palm, Hyphaene thebaica coriacea, and abundant Terminalia spinosa. Many trees and shrubs found in the Grasslands of the eastern coastal strip above are also common in this upland vegetation mosaic as well. Other trees more common to the uplands are Strychnos sp., Manilkara sulcata, Brachystegia sp., Albezia sp., Combretum sp., Dalbergia

sp., Diospyros sp., Mimusops sp., Oldfieldia sp., and many others less prominant.

Examples of bush and troublesome scrub species in the Bushed Grasslands and Bushland Thickets are Acacia mellifera, A. nilotica, A. zanzibarica, Commiphora africana, Terminalia spinosa, and Brachystegia sp.

Understory grasses of both Wooded and Bushed Grasslands are here again repeated from the coastal strip; primarly, Hyparrhenia species dominate. Other species, perhaps owing to greater moisture or different grazing and burning patterns, include Panicum maximum, Digitaria scelarum, Heteropogon contortus, Themeda triandera, Chloris sp., Sporobolus sp., and Aristida keniensis.

Trees and shrubs of the isolated Evergreen Forest islands, besides some of those mentioned above, include Olea africana, Warbargia stuhlmannii, Afzelia cuanzensis, Acokanthera sp., and Ficus sp. In these forest islands are many creepers and liana type species, such as, Euphorbia sp., Smilex sp., and Texaminus sp. Although the forest floor is usually devoid of herbaceous plants, occasional Sansevieria sp. and other succulents do occur. Where breaks in the normally continuous canopy let sufficient light down through to the pink sandy litter-covered forest floor, Panicum maximum is the dominant grass. Apart from lianas and creepers on trees that surround the sharp forest edge ecotone, aspharagus fern is the only other conspicuous vegetative feature. There appears to be little if any concentric vegetative stratification within these forest islands.

The Riverine Forest along the Msangazi River also has a closed canopy condition with very tall trees common to coastal riparian habitats. These gallery type forests are mostly confined to the immediate streamside

are often a function of shallow pans which trap moisture, termite colonies, or similar micro-habitat situations related to soil moisture retention.

The whole of the ranch is covered with subterranean termites Odontotermes sp. except for the broad flood plain of the Msangazi River. These low 30-40 cm dark brown to black hardened vent mounds stand out in sharp contrast to the surrounding light brown sandy surface soil. No evidence of termite mounding was apparent within the more heavily forested or wooded areas. Termite mounds were equally conspicuous in the grazed fly barrier clearings.

Forbs have not been mentioned in the community descriptions but this is not to diminish their importance in the total flora though they are a relatively minor biomass component relative to trees, bush and grass. No unique community relationships seemed to be associated with the forb complement. However, several naturally occurring legumenous forage species are common along the western coastal strip. Common are Stylosanthes fruiticosa and Glycene javanica. Some low shrubs and semi-woody forbs also occur generally throughout the ranch. Examples are Cordia sp., Boscia sp., Croton sp., Grewia sp., Cassia sp., and Euclea sp. A few old Mango trees and an occasional cashew-nut tree can be seen which would indicate some former occupation of isolated tracts of land within the site.

Several unusual plant communities were found throughout the ranch. Some of the larger poorly drained depressions contained aquatic grass-like sedge stands of pure Cyperus sp. Occasionally large such stands are encountered in waterlogged sites on the Msangazi flood plain. Certain reservoirs have rush-like species surrounding them near waters edge.

Some ponds and stock tanks contain floating lilies and "swamp lettus" or "Piatla." Several kilometers beyond the point where the Mzangazi River crosses the northwest ranch boundary, mangrove swamps begin and extend for several more kilometers to the Indian Ocean. The estuary here is a combination of tree swamps, bush thickets, mud flats, and open sand.

PLANT LIST

TREES AND SHRUBS

Acacia ethbaica

Acacia melifera

Acacia nilotica

Acacia paolii

Acacia zanzibarica

Acokanthera sp.

Adansonia digitata

Afzelia cuanzensis

Balanites sp.

Borassus sp.

Boscia sp.

Brachystegia sp.

Combretum sp.

Comiphora africana

Dalbergia sp.

Dichrostachys cinerea

Diospyros sp.

Euphorbia candelabrum

Ficus sp.

Harrisonia abyssinica

Hyphaene thebaica coriacea

Kigelia aethiopum

Manilkara sulcata

Mimusops sp.

Oldfieldia sp.

Olea africana

Sclerocarya caffra

Smilex sp.

Strychnos sp.

Tamarindus indica

Terminalia spinosa

Texaminus sp.

Warburgia stuhlmannii

GRASSES AND GRASSLIKE

Andropogon schirensis

Aristida keniensis

Bothrichloa glabra

Chloris sp.

Cynodon dactylon

Cyperus

Dactyloctenium aegyptium

Digitaria scalarum

Erogrostis superba

Hyparrhenia dissoluta

Hyparrhenia filipendula

PLANT LIST

Hyparrhenia rufa

Panicum maximum

Sporobolus sp.

Themeda triandera

FORBS

Boscia sp.

Cassia sp.

Croton sp.

Euclea sp.

Glycene javanica

Grewia sp.

Sansevieria sp.

Stylosanthes fruiticosa

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APPENDIX 2

REPORT OF TSETSE FLY PROJECT REVIEW COMMITTEE
Tanga-Mkwaja, Tanzania, January 24-25, 1977

The research program on the use of sterile males of *Glossina morsitans* is now concluding Phase II, the development of fly production methods and preparation of a field test site. Since the last review, the project has completed its building activities, demonstrated the capability for rearing sufficient flies for a release operation and initiated population analyses and field studies pursuant to initiating the Phase III; a field trial during the latter part of calendar year 1977.

The current status of the program is adequately described in the working papers presented by the research team staff for the Review Committee (Appendix 2). Following a thorough review of this material, close inspection of the facilities at Tanga, and a visit to the field site, the Committee recommends the implementation of Phase III. The Committee debated the remaining requirements and the operational planning for Phase III. A brief summary of the agreed procedures follows:

Fly rearing and host animal production at Tanga

The fly colony is being increased so that it will reach the maximum level of 45,000 females and 15,000 males sometime from June to September. When this is achieved approximately 35-45% of the females and 25% of the males produced will be required to maintain the colony at a stable level of production. Depending on the reproduction characteristics of the colony at that time, between 800 and 1,200 males will be available for

daily release. These numbers will provide a daily release rate of 8-16 per square mile depending on the proportion of flies released in the test and barrier zones.

The Internal I and II Tanga colony strains will be field-tested to determine if they have similar survival and dispersal characteristics and, if so, the less productive Internal II colony will be disbanded. Recent genetic studies have shown that the Tanga strains are similar to the Mkwaja strain; therefore, no further attempts will be made to incorporate the Mkwaja strain into the rearing program. However, propagation of the mutant marker strain (now 1,200 strong) will continue and field and laboratory tests (Mkwaja and Seibersdorf) will be conducted to assess its viability and competitiveness.

To provide replacement stocks in the event of a diseaster in one of the insectaries, a back-up colony of the internal I strain is being maintained at the IAEA Seiberdorf laboratory. This strain, currently 3,500 strong, will be increased to 10,00 females prior to initiation of the release program. The back-up colony will be able to supply up to 13,000 pupae upon demand plus 430 daily threafter. This colony is being maintained exclusively on preserved horseblood using membrane feeding techniques, and has a somewhat lower mean pupal weight than animal-fed flies (28mg vs. 30mg, respectively). However, its fecundity currently exceeds that of the animal-feed colony by about 23%. Tests will be conducted to determine the reason for this large difference in order to improve the fecundity of the animal-fed flies. The advisability of

initiating a second back-up colony (5,000 females) at Langford is under consideration. When sufficient numbers are available it may be possible to test flies of the back-up colonies in the field. Cytogenetic studies will be conducted at Langford to determine the similarity between the back-up colonies and the parent Tanga stocks.

Because of the presence and importance of G. pallidipes at Mkwaja Ranch, an attempt will be made to establish a colony of this species in Tanga. This species will be maintained as a small, research colony in anticipation of a future increase for release purposes after the control of G. morsitans has been achieved.

Approximately 550 goats and 110 rabbits will be required for maximum fly production. These numbers include provision for reserve and sick animals. It is anticipated that adequate numbers of both hosts will be on hand by March 1977. The rabbits will be utilized in one or more insectaries as hosts for the stud males. Female flies will be fed on goats routinely, but the presence of rabbits provides an alternate host for some of them if required. To prevent disruption in the availability of these hosts, continued emphasis will be placed on daily veterinary surveillance, provision of adequate insecticide-free foods, controlled herd management and breeding techniques. In addition, goat barn modification will be undertaken to upgrade the goat quarters in Insectaries I & II to that of Insectary III.

Handling, Transport and Sterilization

Studies at Tanga have confirmed the suitability of irradiating pupae in a nitrogen atmosphere. Further work is scheduled to determine methods of pupal storage to obtain optimum numbers of viable sterile males for release, and at the same time conserve females for colony purposes.

The current concept includes allowing the bulk of the females to emerge at Tanga, then cooling the remaining pupae (mostly males) for transport to Mkwaja Ranch, where they will be irradiated and released prior to adult emergence. Testing will include an assessment of stockpiling male pupae to reduce the number of trips required between Tanga and Mkwaja.

Barrier Methodology and Fly security at Mkwaja

Insecticidal Barrier:

The 1 Km wide cleared barrier will be completed between March and June. The barrier will be reinforced along the outside perimeter with residual applications of 5% DDT on the lower 10ft. of trees greater than 4 inches in diameter and on the undersides of the lower branches. Based on available information regarding the width of a dialdrin barrier required in Tanzania and Uganda, the initial barrier testing should utilize a 300m. treatment swath. This test should include at least 3 linear miles and perhaps cover the entire portion of the barrier separating the treatment and control areas. Treatments should be at bimonthly intervals

and bioassays will be conducted to assess the degredation of the residue.

Several techniques should be utilized to determine barrier effectiveness and it must be recognized that failure to detect fly movement across the barrier will not necessarily demonstrate that it has not occurred. Fly movement serves as the major means of assessing the effectiveness of the barrier. Laboratory-reared flies will be marked as they emerge outside the barrier, wild flies will be marked in the course of normal flyround activity, and addtitional flies will be captured, marked and transported to the outside of the insecticide treated barrier for release. This activity should be continous for a 6 to 8 week period and, if no migration is detected, should continue thereafter but on a less intensive basis. Several bait animal capture stations will be established along the inside perimeter of the barrier and manned during week-days during the tests. In addition, flyround surveys and possibly electric grid trapping will be used to capture flies and detect migrants. All migrants from outside the treated barrier will be placed individually in tubes, killed in the sun, and chemically analyzed for insecticidal content.

If the 300m insecticidal barrier is not successful, the width will be increased and the testing repeated. In the event that the barrier is still not completely effective, a maximum barrier of 1 km will be evaluated; if this treatment is sufficiently effective, the releases will be conducted using a 1 km barrier. The full insecticide barrier

will be completed at least 6 weeks before the initial population suppression.

To encourage an adequate assessment of the release of sterile males, evaluations will be conducted in both the outer perimeter of the release area and in the inner core. Evaluating the information in this manner may make it possible to determine the influence, if any, of immigrant flies and thus judge more accurately the efficiency of the released males.

Fly Security

Fly gates and/or deflying chambers will be established at the access roads to the release portion of the ranch. Movement by ranch animals between the north and south sections and in the cleared barriers will be terminated prior to the inital suppression of the fly population.

Population and fertility assessment at Mkwaja Ranch

Flyround activity will be continued throughout the pre-release, release, and post-release periods, although the total weekly flyround activity may be reduced. In addition, bait stations will be established as will the correlation between screen and cattle flyround capture efficiency. These techniques, supplemented by other trapping methods that may become available, will provide data for estimates on population density for morsitans and pallidipes males as well as apparent density

estimates and male:female ratio. During the actual release program the irradiated males will be automatically marked as they emerge from the puparia and thus it will be possible to determine sterile male to wild male ratios directly and to identify the released females.

Female fertility assessment will be conducted by the following methods. The incidence of reproduction malfunction will be observed by dissection of captured females and compared to baseline data and also to observations made concurrently in the control area. Secondly, if feasible, captured females will be maintained for reproductive assessment in the laboratory.

Additional population characteristics will be monitored including analyses of blood meals with both pallidipes and moristans and the susceptibility of morsitans to toxaphane residues on treated cattle.

An assessment of trypanosome transmission will be made by conducting or contracting work on infection rates in both species of fly, random sampling of up to 10% of the cattle herd, and obtaining such information on infection rates among wild animals as is practical.

Fly releases will be continued for a minimum of 6 months following the last capture of a sterile wild female (if the barrier is completely effective) and surveillance will continue for an additional 6 months. If the barrier is completely effective, the continuation of release for such a prolonged period may not be required.

Population suppression at Mkwaja

Based on preliminary estimates of the population density of G. morsitans at Mkwaja Rach, 3 ULV insecticide applications will be required. It is estimated that if 90% control is achieved with each application, it will be possible to release daily 2 times to 4 times more sterile males than the number of wild males that will be emerging from pupae. spraying will be conducted in the release area with minimal overlap into the barrier zones. Endosulfan will be used at a rate of 30gm/ha per application, about 600 kg A.I. per allication. If feasible, the application will be applied with the Cessna 185 aircraft currently based at Arusha. Additional equipment for the aircraft will be procured from the commercial operations contracted to perform the work and an experienced consultant will be obtained to oversee the application program. The current estimate calls for the interspray interval to be 15-18 days. The most opportune time for the operation appears to be between September and December, when the foliage is at a minimum and prior to the foliage flush that normally preceeds the rains.

The effectiveness of each application will be monitored by standard flyrounds and/or standing bait fly captures. In addition, variations in control levels due to differences in the bush canopy will be determined by bioassay at selected sites.

Release Sequence at Mkwaja

Following the first aerial spray application sterile males may be released in areas of maximum fly density to obtain some level of reproductive control on the subsequent females emerges. These released males will be destroyed by the second application, but by that time they should have exerted some effect. Similar releases may be conducted after the second application. Following the third application the releases will extend throughout the entire release zone, with limited numbers being released in the barrier zone. Current calculations indicate that it will be possible to achieve a ration of 2-4 sterile males to each wild male at that time. This should cause an immediate reduction in reproductive capacity and significantly reduce the size of the subsequent generation. Releases will be continued at the maximum rate possible, with due consideration for irregular density distribution through the release zone, in order to obtain the maximum rate of population decline.

In all probability releases will be made daily, with each release site being serviced from 1 to 3 times weekly. Pupal irradiation will be conducted at Mkwaja Ranch to take maximum advantage of the stimulated emergence caused by irradiation. The irradiated pupae will be packed in small containers under a layer of inert material containing flourescent power. The containers will be distributed to some 250-300 selected

release sites along the existing flyrounds and in the barrier zone. The actual schedule of releases and distances between release sites will be determined following upcoming field evaluations of the released flies. In addition to the flourescent powder mark on the released flies, a mutant marker strain may also be utilized to help monitor the effectiveness of the release insects.

Completion of Programme:

The effectiveness of the sterile male programe should be evident by the end of calendar year 1978. Although releases may be continued after that time, an analysis of the operational feasibility and economics will be possible early in 1979. Thus, the project staff should at that time have their data prepared for a critical evaluation by the Review Committee, and subsequently by other interested parties and organizations. At that time final preparations should be undertaken to renew the programme for such large scale operation as will have been decided upon between now and then. Potential areas for future operation discussed by the committee include Mkwaja(*pallidipes*), Zanzibar (*G. austeni*), Mafi Island, the West Lake Project and the Handini area.

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October 1976

INDUSTRY COOPERATIVE PROGRAMME

and

ANIMAL PRODUCTION AND HEALTH DIVISION

Second Session of the Joint FAO/ICP Task Force on Animal Trypanosomiasis and Tsetse Control - Rome, 30 March 1976
0930 - 1600 hrs. Philippine Room (C-277), FAO Headquarters

Third Draft Report on Insecticides and Application Equipment for Tsetse Control

(presented by Professor P. Haskell, Director,
Centre for Overseas Pest Research, London)

This report has been prepared by the Centre for Overseas Pest Research (COPR) in accordance with the terms of reference set out below at the request of the FAO/Industry Task Force on Tsetse Control.

The COPR, in cooperation with the FAO Headquarters Animal Health Officer (Trypanosomiasis Control), the WHO Division of Vector Biology and Control, interested national and international institutions and private companies interested in tsetse control, will:

- Make a review of information on insecticide formulations and application equipment used for tsetse control according to the various control techniques.
- Provide technical documents describing the requirements of insecticide formulations and application equipment.
- Prepare a coordinated research programme aimed at improving the technology of tsetse control.
- Submit a report to the next meeting of the FAO/Industry Task Force on Tsetse Control.

W/K2107

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PART I. REVIEW OF INSECTICIDES AND APPLICATION EQUIPMENT FOR TSETSE CONTROL

INSECTICIDES

Background

1. When DDT became available in 1945 the East African Tsetse Research Organisation soon showed in the laboratory that tarsal contact with a sprayed surface for a few seconds could be lethal to tsetse flies (105), but subsequent field trials with treated oxen as bait animals were not successful because they were unable to compete as tsetse hosts with the game animals and they had to be re-sprayed at too frequent intervals (8, 107). Meanwhile, also in 1945 in East Africa, the Colonial Insecticides Research Unit (the forerunner of the Tropical Pesticides Research Institute) showed that deposits of DDT and BHC on leaves were lethal to tsetse flies after a short contact, and demonstrated in field trials on islands in Lake Victoria that single ground applications to a very small proportion of the vegetation reduced fly counts by 50-80% for 1-2 weeks (95). Repeated applications to maintain a toxic deposit for longer than a pupal period were necessary for a greater and more permanent reduction (108, 109). Dieldrin was first tested in 1955 (18) and soon replaced DDT in residual sprays on vegetation in Kenya (40). Residual treatments of vegetation from ground spraying equipment were begun in West Africa in 1953. Since these early operations until the present time DDT and dieldrin have continued to be almost exclusively the insecticides used for residual treatments of vegetation in ground spray operations. The only real changes have been in techniques to improve effectiveness and reduce costs, by reducing dosages and by more discriminative and selective applications (21, 26, 28, 48, 63, 64, 74, 75, 76, 89, 90, 110).

2. Applications of insecticides from aircraft for tsetse control have been made since 1947 and the first successful scheme was carried out with DDT and BHC in South Africa where air-spray operations with both fixed-wing aircraft and helicopters were combined with other control measures over a period of years to eradicate G. pallidipes (101). A programme of research on aerial spraying for tsetse control began in 1948 (para. [illegible]) at the Tropical Pesticides Research Institute (TPRI) (13, 17, 19, 35, 49, 50, 51, 52, 53, 54, 55, 56, 68), and this has been the

forerunner of airspraying techniques employed in Zambia (para. 68) and Botswana (para. 63) today. DDT and BHC, the first insecticides used, were replaced by dieldrin and more recently by endosulfan at rates as low as 0g in 0.03 l/ha (61, 82). Since the late 1960's, techniques have been developed for the application of a residual insecticide to vegetation from a helicopter (91).

Resistance

3. Insecticides used in tsetse control operations on any scale from the ground and from the air have been limited to DDT, BHC, dieldrin and endosulfan. These are all organochlorine compounds. Where insecticides belonging to this class have been used to control other insect vectors and crop pests, resistance to them has frequently developed quite quickly and become a serious problem. Resistance to insecticides in tsetse flies has not been reported yet. Some tests in N. Nigeria in 1968 indicated that the susceptibility of a population of G. palpalis to DDT and dieldrin had remained fairly stable over a period of 4 years,(86) but no systematic monitoring programme to detect resistance has been carried out in West or East Africa and there is no reason to expect that it would not develop sooner or later if populations are put under greater insecticidal pressure.

Environmental effects

4. Restrictions have been put on the use of organochlorine insecticides in some countries because of persistence in the environment and undesirable side effects on non-target organisms, and these compounds may become less readily available or acceptable for tsetse control. Destruction of birds and wildlife immediately after tsetse control operations with organochlorine insecticides have been recorded (41, 65, 67). There was a general decline in the prominence of certain insectivorous birds a year after a single application of dieldrin in Nigeria, but most of the species affected then recovered to pre-spray density (66), and monitoring in Uganda showed that the spray programmes were not leaving dangerous doses of dieldrin in the soil or vegetation. An ecological assessment after aerial applications of endosulfan in Zambia showed no lasting adverse effect on the

insect fauna, and similar operations in Botswana have so far produced no adverse effects on people, cattle or fish. The various studies to date indicate that residual spraying of a single heavier dose of insecticide to a selected and restricted part of the vegetation is more likely to have an impact on non-target organisms than is sequential aerial spraying.

Search for new compounds.

5. A systematic search for insecticides that could replace the organochlorine compounds in tsetse control operations when necessary was begun at the TPRI, Arusha, (9, 10, 12, 14, 15) and has continued at COPR as a part of the WHO Evaluation Programme (43, 46). Some of the candidate insecticides have also been tested recently at the Nigerian Institute for Trypanosomiasis Research (87).

6. In laboratory bioassays of the toxicity of organophosphorus compounds to tsetse by topical applications in solution, none is found to be appreciably more toxic than endosulfan and dieldrin and only a few are as effective as they are. These include OMS-1825, OMS-1504, OMS-1283, fenthion, chlorfenvinphos, dicrotophos and crotoxyphos, while phosmet, naled, dichlorvos, tetrachlorvinphos, bromophos, jodfenphos and fenitrothion are from 2 to 4 times less active. OMS-1825, OMS-1504, OMS-1283, tetrachlorvinphos, bromophos and jodfenphos have the advantage of low mammalian toxicity. Naled and dichlorvos are too volatile.

7. Propoxur and bendiocarb, the most active of the N-methyl carbamate tested, and two di-methyl carbamates pyrolan and dimetilan, are similar to or slightly less toxic than endosulfan and dieldrin.

8. Tsetse are susceptible to natural pyrethrin (10) and to a number of synthetic pyrethroids including resmethrin and its constituent isomers bioresmethrin and cismethrin, permethrin (NRDC 143), NRDC 149, NRDC 156 and NRDC 161 (6). NRDC 161 is outstanding and is 100 times as effective as dieldrin to G. austeni. Resmethrin resembles natural pyrethrin in that it is unstable on exposure to light, but permethrin and NRCD 161 are light stable and involatile and at present have the greatest potential as residual insecticides for tsetse control, although some pyrethroids may be more suitable for sequential low rate applications than for single dose residual sprays because of their high toxicity to fish.

Susceptibility of different species.

9. Variation in susceptibility of different species to an insecticide is

another important factor in field operations. As early as 1947 a 4-fold difference in susceptibility to DDT was found among 12 species and subspecies between the most susceptible G. pallidipes and the least susceptible G. brevipalpis, G. longipennis and G. fuscopleuris (105). G. swynnertoni is more susceptible than G. morsitans but G. austeni, G. morsitans, G. palpalis and G. longipalpis appear to be similar in their tolerance to a number of compounds (43, 87) although few comparisons have been made by the same method under the same conditions.

10. The susceptibility within a species to an insecticide can vary according to sex and physiological condition either because there is a real difference in the dose actually required to kill or because there is a difference in the dose reaching the flies e.g. pick-up from a deposit by a fully-fed or a pregnant female may be greater than that by a teneral fly because the ventral surface of the abdomen as well as the tarsi makes contact with the treated surface.

11. Teneral flies of either sex and old fed males are generally equally susceptible to insecticides applied in solution by topical application (11, 43). All are more susceptible, however, than pregnant females to the organochlorine insecticides DDT, dieldrin and endosulfan (11,43,57), and 4 to 9-fold increases in tolerance in old females have to be taken into account in field operations with these insecticides.

12. Laboratory tests to date indicate only a small increase in tolerance in old pregnant females to natural pyrethrins and a synthetic pyrethroid resmethrin, and no increase in tolerance to the organophosphorus compounds fenthion, tetrachlorvinphos and bromophos, and the carbamate propoxur (11,43,87).

Field trials

13. Some of the compounds showing high toxicity to tsetse flies in laboratory tests and referred to above have already been subjected to limited field trials. In 1966 in northern Tanzania three aerial applications at 3-week intervals of undiluted technical fenthion caused more than 90% reduction in tsetse populations in the 4 weeks after treatment, but no further trials have been reported (58).

14. In 1967, six aerial applications of 0.4% w/v solution of natural pyrethrins

synergised with 2% piperonyl butoxide in power kerosene were made at 3-week intervals in Tanzania. Populations of G. pallidipes were reduced by 95% after three applications but subsequent applications did not significantly reduce fly numbers. It was considered that unfavourable meteorological conditions during these applications and full leaf cover were the main factors responsible for the lack of effect, and further work was recommended on the basis of the good results of the first applications (59). Subsequent aerial applications of natural pyrethrins at a higher concentration did not give high reductions of G. swynnertoni and G. pallidipes populations (97,98) although two ground treatments reduced the population of G. swynnertoni by 98% (96). In aerial spray trials in Botswana in 1975, natural pyrethrins at 0.6 and 1.2 g/ha had no effect on the G. morsitans population. In the previous year in Botswana the same dosages of the synthetic pyrethroid bioresmethrin applied from the air in 2% and 4% solutions in diesoline were also too low and had little or no effect on the population of G. morsitans (71).

15. Earlier, applications were made from a helicopter in the Republic of Mali of cismethrin, bromophos, jodfenphos, fenitrothion and tetrachlorvinphos for aerosol contact of the flying adults in the gallery forest, and of tetrachlorvinphos and methoxychlor for residual contact (24). Operational problems limited the scope of these trials, and additional tests with these materials could be valuable. The trials emphasised the need for further studies of the penetration of spray drops into the dense vegetation of gallery forests (60) and on the resting behaviour of tsetse flies, particularly at night.

Formulations

16. Residual spraying techniques employ DDT and dieldrin as emulsions and suspensions. The concentrates from which these are prepared are those normally used for public health work and the only example of a formulation specially made and used for tsetse control is the dieldrin 15T emulsion concentrate. This involves a modification of the surfactant part of the standard dieldrin 180g/l e.c. which allows the preparation of relatively concentrated emulsions containing up to 5% active ingredient without inversion of the phases. Otherwise formulations which meet the WHO specifications (Specifications for Pesticides used in Public Health, 1973) have been satisfactory.

17. Aerial spraying methods have used high volume rates of dieldrin emulsion

(91) but aircraft normally distribute low or very low volumes of concentrated solutions of dieldrin, DDT or endosulfan with the intention of directly hitting the flies. The desired efficiency and economy are obtained by using insecticides which are very toxic to tsetse flies, the optimum range of droplet sizes and suitable choices of aircraft operation methods and meteorological conditions. An important factor controlling the droplet sizes in the aerosol as it reaches the standing vegetation or the ground is the volatility of the solvent used to dissolve the insecticide and East African experience has shown that this should not be high, otherwise droplets become too small to reach the target efficiently. Kerosene with a boiling range of about 150 to 250°C produces less effective aerosols than diesel oil which has a wider range of around 200 to 350°C and the latter has been used as a diluting or primary solvent. Despite these results, the more recently developed and currently favoured endosulfan solutions (61,82) are prepared by diluting a 35% emulsion concentrate to 20% with Shellsol AB. This solvent has a boiling range of 186 to 214°C and a substantial proportion of the spray volume is presumed to be lost during the time it is airborne especially as the solvent of the concentrate is even more volatile. However, at the time of this development work the formulation had to be chosen from those made for other applications. Also, volatility was necessary to allow suitable droplet sizes to be formed by evaporation of coarser sprays produced by the available equipment. Less volatile solvents are now being investigated (see paragraph 18). Insecticides which are themselves liquid, such as fenitrothion and malathion, do not require formulation for application at ultra-low-volume rates, have not been used against tsetse.

18. There has been little attept during the last 20 years to improve formulations for the insecticide application in tsetse control. A good reason for this is the desire for economy. It is cheaper to employ concentrates which are already being used for the control of other pests and to dilute these with locally available petroleum solvents than to transport specially prepared solutions over long distances. However, special formulations are being produced and the use of more involatile materials is being studied by some chemical companies. For example, trials with dieldrin and endosulfan in various solvents have been carried out in Nigeria and Botswana. The Nigerian tests involved selective residual spraying of dieldrin to vegetation by helicopter at 800 g/ha to approximately 10% of the total area. Bioassay of the residues are made with captured flies. In Botswana, five applications of endosulfan are sprayed at 6 g/ha per treatment, the aim being to obtain direct contact of insecticide on the flies either on

the wing or in their resting sites and changes in the natural fly population are measured. Both investigations suggest that the less volatile solvents give the best results although the reasons for the improvements are not clear because lower volatility influences both the persistence of insecticide in the residues and the particle size distribution of the spray. The solvents used are essentially non-volatile, e.g. vegetable oils (cotton seed oil, arachis oil or rape seed oil), Genomoll (2-ethylhexylphthalate) and Dutrex 217 (an aromatic product from petroleum). These have been compared with diesel oil which is partly volatile and Shellsol AB which is relatively very volatile. It is worth noting that although 'non-volatile' or 'low-volatile' solutions are mentioned in reports only part of the solvents they contain can correctly be given this description. Extremely low volatility means high viscosity and the solutions therefore contain other more volatile solvents to reduce viscosity to a sprayable level and, in some instances, to ensure that the active ingredient remains in solution during storage.

GROUND APPLICATION EQUIPMENT

Introduction

19. Anyone with access only to the published records of ground spraying against tsetse would have difficulty in discovering just how the insecticides are applied. This is being remedied to some extent by the publication of more information on pesticide application equipment a good deal of which has relevance to tsetse control. COPR and the Overseas Spraying Machinery Centre (OSMC) in collaboration with other UK scientific units through the Ministry of Overseas Development Natural Resources Advisory Coordinating Committee (ODM NRACC) Sub-Committee on Pesticide Application Overseas (SC) helps in the promotion and co-ordination of pesticide application research and development in relation to the demands of overseas countries. Assessment of spraying machinery is ongoing research at OSMC (79) and many of the tests carried out are based upon recommendations by WHO (30, 112).

20. Spraying equipment is used to disseminate pesticides as liquids in the form of aqueous suspensions, emulsions and solutions. It is not possible to list all the equipment in current use or which is available, but the apparatus mentioned below has been used in major control operations; e.g. aerosol dispensers are used at fly pickets, [illegible] machines although employed in the early days have

now declined in use whereas a variety of hydraulic energy and gaseous energy equipment is still in regular service.

Hydraulic energy equipment

Spray nozzles

21. There are three basic pattern shapes produced by hydraulic energy nozzles; the falt fan, the solid cone and the hollow cone. The limitations of the fan pattern for tsetse work are reflected in the very few occasions on which it appears to have been used. In a campaign against G. palpalis (39), the Eclipse[1] sprayer was used fitted with a lance that gave a fan-shaped spray for treating the leaves and stems of plants along paths. One difficulty which arises with these nozzles is that the width of the fan has to be orientated in order to cover the surface to be sprayed.

22. Cone-shaped sprays are produced by nozzles which consist essentially of a swirl plate with angled slits or holes which produce a vortex in the flow of insecticide, causing it to issue from the orifice in the form of a solid or hollow cone of spray depending on the presence or absence of a central hole in the core. Whether the solid cone nozzle has ever been used in tsetse control is uncertain.

23. The hollow cone spray nozzle is in general use and either a constant or variable spray width can be produced. For the former, the actual dimensions are determined by the design of the swirl core, the size of the nozzle disc orifice and the operating pressure. The practical limitations of these nozzles is that when spraying tree trunks or individual branches, the position of the nozzle, in relation to the surface being sprayed, must be constantly adjusted to ensure that a swathe of insecticide of the required width is obtained (27).

24. Accurate and therefore less wasteful application can be achieved by a skilled operator using a spray lance (sometimes referred to as "gun") emitting a cone of spray whose shape can be instantly adjusted to fit the width of the object being treated. This can be achieved by altering the length of the swirl chamber. The angular width of the cone, at a given pressure is inversely proportional to the length of the chamber between the swirl block and orifice disc. Alternatively wastage can be avoided by adjusting the distance between

1 ECLIPSE SPRAYERS LTD., Rawlings Road, Smethwick, WARLEY, West Midlands B67 5AB, United Kingdom

the nozzle and the target surface but this may necessitate moving the nozzle more rapidly when close to the surface.

Spray lances.

25. Two types of spray lance are in general use. One has a shut-off valve in the handle, for controlling the flow of insecticide and produces a constant or variable cone, depending upon the type of nozzle fitted. With the other, the shape of cone is adjusted from the handle by means of a control rod inside the lance.

Shut off valve models.

26. These consist of a trigger operated, instantaneous, shut-off valve which with tube and nozzle form the lance assembly. To produce a constant shape cone, the nozzle assembly contains a swirl cone, an orifice disc and a screw retaining cap. The shape of the cone produced, for a given pressure, is related to both the design of the swirl plate and the size of the orifice in the disc. Variable cone nozzles consist of a nozzle body, attached to the end of the lance by means of an adaptor. Variations in the shape of the cone are produced by altering the length of the swirl chamber between the core and the disc, by screwing or unscrewing the cap. Leakage of insecticide down the lance from the nozzle is prevented by an 'O' ring, immediately above the threaded portion of the body.

27. The CP 601[2] spray gun has been used in some countries. This consists of trigger operated shut-off valve, with a brass body, a plated steel trigger, a brass tube, 58.5 cms in length with a 45° bend near the end and a single cone spray nozzle no. 520/P. The nozzle has a plastic swirl core, of which only one model is available, a stainless steel nozzle disc and a plastic nozzle cap. Six different orifice sizes are available, with diameters ranging from 0.79 to 2.38 mm., but in both Nigeria and Uganda disc No. 12 with a 1.19 mm orifice is fitted.

28. Also in this category is the Stoprex spray gun[3]. This has a thumb trigger, in contrast to the models previously described, all of which have a four finger trigger for operating the shut-off valve. The lance and constant-shape cone nozzle assembly are however similar to those of the CP601 but the Rex Variable

2 Cooper Pegler Ltd. Burgess Hill, Sussex RH15 9LA. United Kingdom.

3 Berthoud, 48 Rue Victor Hugo, 69002 Bellville-Sur-Saone (Rhone)France.

Nozzle[4] is of a different design. Variations in swirl chamber length are made by rotating a collar to which the same stainless steel orifice disc and plastic nozzle cap as those used for hollow cones are fitted.

Control rod models

29. Spray guns of this type are intended for use in situations where frequent and often rapid changes in the width of the spray pattern are necessary, e.g. when treating the trunks of different trees and the underside of branches at varying distances from the operator. As with the variable cone nozzles described above, pattern shape is changed by altering the length of the swirl chamber. The disc is fixed but movement of the core is achieved by the control rod. The CP700 Spray Gun[5], is one example of this model which has been extensively used in Uganda, but is no longer available.

30. A somewhat different mechanism for adjusting cone shape is found in the GunJet No 12 and No 14[6] spray lances whose use in Botswana has been reported (3). The essential difference between these and the No. 700 is that changes in the swirl chamber are made by rotating the control rod. On rotating the handle the swirl chamber is progressively opened and spray is emitted, at first in the form of a short broad cone. As this movement is continued the cone becomes progressively longer and narrower until when a complete circle has been turned and the swirl chamber is fully open and the spray is emitted as a solid stream. The cone dimensions are related to operating pressure and orifice size and two types of fitting may be used for producing hollow cones. One is a stainless steel disc, intended for the higher rates of application, while for lower outputs the disc can be replaced by a ConeJet spray tip[7], of which ten sizes are available.

31. Another lance in which the spray cone is adjusted by means of a trigger-operated control rod has been used with a Platz vehicle mounted sprayer in Zambia. The output of each lance is controlled by the manual operation of the trigger and can be varied between a very fine cone spray and a solid jet (37). The maximum output (from one lance) is about 4 l per minute with a 2mm disc orifice and 2.18 per minute with a 1.5 mm disc orifice. The maximum throw is about 15m in still conditions.

4 Berthoud, 48 Rue Victor Hugo, 69 Bellville-Sur-Saone (Rhone) France.
5 Cooper Paglor Limited, Burgess Hill, Sussex, RH15 9LA, United Kingdom.
6,7 Spraying Systems Co., Schmale Road, Wheaton, Illinois 60187, U.S.A.

Hand operated machines

32. In contrast to the extensive use made of hand compression sprayers few organisations have adopted the lever-operated type, which are lighter but less robust. Unless a pressure regulating device is fitted, considerable variations in output rate can occur because of changes in lever operation, which is affected by operator fatigue. Operators have also found continuous pumping more tiring than the periodic pumping of compression sprayers and a further disadvantage is that they are unable to use both hands freely to gain access to difficult places or to steady long lances when spraying the undersides of high branches, one hand being required for pumping.

Pressure-retaining compression sprayers.

33. Extensive use has been made of these machines, because they maintain pressure, and consequently less effort is required to operate them than non-pressure retaining sprayers. The high operating pressure also reduces the tendency to blockages. This type of sprayer can be rapidly charged by means of a detachable pump and maintains air pressure after the spray has been discharged; further pressure loss is prevented by a floating ball valve.

Two types of Colibri[8] are still used in anti-tsetse operations, each using a different type of charge pump. The Leo-Colibri[9] has its own detachable hand pump, whereas the Favori-Colibri[10] machines are charged by means of a large manual or motorised pump which can charge several machines simultaneously. This can be time saving especially where operators are working near tracks (29) or in close proximity to each other, e.g. when treating narrow zones of riverine forest (64).

The detachable pump is another favourable feature of Colibri equipment because it reduces the weight and consequently operator fatigue, a matter of some importance in highly selective operations where accuracy is essential. In Uganda, where the Leo-Colibri is still in service, each sprayer operator is accompanied by a porter carrying both a reserve supply of insecticide and a charge pump. In Nigeria, a group of sprayers are serviced by a single mobile manual Favori-Colibri hand pump. The Colibri has been used also in the Central African Republic (34).

8, 9, 10 Vermorel - Out of Production.

34. Non-pressure retaining sprayers have been widely used, often in preference to pressure retaining sprayers. This has been due to their lower cost, the non-availability of suitable pressure retaining models and the need to stock fewer spare parts.

35. Some of the first insecticide trials in Uganda (95) were carried out with a Kent[11], sprayer. In the past this sprayer has seen brief service in East (38) West (29,76) and Central Africa (32), but no reference has been found as to the model preferred. Three have been in production for many years, with maximum working capacities of 4.5, 9 and 13.6 l. The pump cylinder is of brass, tinned inside to prevent corrosion and is filled through a fairly small opening in the cylinder, which can be closed with a plug.

36. Another non-pressure retaining machine is the Warley[12], which is very similar to the Kent. This too is filled through an opening but sealed with a cap. In Uganda it was replaced by the Leo-Colibri, before large scale spraying operations got under way, but its use in other countries is referred to by several authors (39,78,81). Like the Kent, there are three sizes of Warley sprayers of similar working capacities.

37. When the Leo-Colibri went out of production, a suitable pressure-retaining alternative could not be found. However, in both Uganda and Nigeria, the CP201[13], was then used, based on a Gloria[14] machine with the same number. As with all non-pressure retaining sprayers, the pump remains in the machine while spraying is in progress. Like the Kent and Warley it was filled through an opening in the top of the cylinder provided for this purpose and closed with a plug. In its commercially available form the CP 201 was found to be much less comfortable to carry than the Leo-Colibri. Its extra weight was a factor but the low position of the upper sling swivel support band as near the top of the tank as its curvature allowed. The commercial life of this sprayer was however short and by 1971 it had been replaced by the CP 148[15].

38. The tank of the CP 148 is of stainless steel and the greater resistance to corrosion of this material may be an asset, although with proper care the corrosion of brass tanks is negligible.

11 Four Oaks Spraying Machine Co Ltd. Four Oaks, Sutton Coldfield, Warwicks, UK.

12 Eclipse Sprayers Ltd. Rawlings Road, Smethwick, Warley, Worcs., United Kingdom.

14 Gloria-Werke PCB 109, 4724 Waderisch-i-Westf., West Germany.

13,15 Cooper Pegler Limited, Burgess Hill, Sussex, RH15 9LA, England.

The tank (13.6 l capacity) provides greater tensile strength and the thinner sheet metal reduces its weight (7.4 kg). How well these thinner walls stand up to the falls which inevitably occur when treating vegetation on a rugged terrain, remains to be seen. Unlike any of the machines referred to above, the CP 148 does not have a separate filling opening. Instead, the pump is removed and insecticide is poured in through that opening, with the aid of the fairly large plastic funnel. This is firmly attached to the machine and is extended to surround and protect both the pressure gauge and the safety valve.

39. Other models with smaller tank capacities which have been used in African countries (33,34) are the Muratori (10)[16], the Galeazzi (10 and 12 l)[17] and the Hudson x pert [17a] which also proved satisfactory.

40. A choice of either diaphragm pump or piston pump models such as the Cosmos[18] is available and both have been utilised for spraying operations. There is one published record of the latter type (103), though these models have been used in Zambia. The Cosmos, has a stainless steel, 16 l capacity, tank but the pump, which includes a paddle agitator, is of polyamid plastic.

41. In contrast to other lever-operated machines, the Kestrel[19] (21), has a pump fitted to the outside of the tank.

42. A very different machine is the CP 3[20] which is now in service in Zambia and Uganda having replaced the Polyclair[21]. The polypropylene plastic body has a working capacity of 18 l and mounted underneath it is a pump which is basically of the diaphragm type but the upper diaphragm support has been so designed that it acts as a piston. The compression cylinder is not a separate component, but is moulded in one piece with the pump body.

Pressure regulators.

43. Few authors refer to the working pressures used when spraying, and the figures quoted are variable (73,85). When the fitting of a constant pressure device is to be recommended (16), an on/off tap to the outlet valve is necessary so that faults in the machine can be rectified without loss of spray liquid. Pressure regulators were once used extensively in Nigeria but were later dispensed with

16 Manufacturer unknown
17 Firma PAOLO GALEAZZI S.p.A. Rome Italy
17a H.D. Hudson Mfg. Co., 154 East Erie St., Chicago, Illinois, 60611, USA
18 Berthoud, 69 Belleville-Sur-Saone (Rhone), France.
19 E. Allman and Co Ltd., Allman Patents Ltd. Birdham Rd., Chichester, Sussex PO20 7BT, United Kingdom
20.21 Cooper Pegler Ltd. Burgess Hill, Sussex, RH15 9LA, United Kingdom

because spray deposit was more effectively controlled visually by the operators. A simple alternative to the pressure control valve is the disc flow regulator which has been incorporated in some sprayers.

Motorised machines

44. The use of a small motorised pump is referred to in an account of spraying operations along the Malawa river on the Uganda/Kenya border in 1956 (88). This type of pump was used from a dinghy and was capable of throwing a variable jet of spray to a distance of 8 m. It is believed that the 700 model spray guns were used in conjunction with the pump and more recently, the banks of the same river were sprayed again from a boat. The insecticide was applied with similar guns but was supplied from a different type of motorised sprayer. This sprayer consisted of a high-pressure diaphragm pump, powered via a reduction gear by a 4-stroke petrol engine. Two delivery hoses were attached and an adjustable regulating valve gave a range of pressures from 10 to 30 kg/cm^2.

45. In Zambia the use of powered pumps has been the standard practice since large-scale eradication campaigns were implemented. The equipment employed was a Platz spray unit mounted on Unimog model 411 tractor. The unit consists of a 3-stage piston pump driven by a pto shaft. Insecticide was supplied from an 800 l tank mounted on the vehicle and was delivered through two hoses at a constant pressure of 30 kg/cm^2 to a pair of lances. These were held by two operators sitting on swivel seats at the back of the loading platform but in rough conditions they walk alongside the vehicle (2,36,37). This type of equipment is, in comparison to manual methods relatively expensive and wasteful (81) and is likely to be replaced by knapsack sprayers.

Gaseous energy equipment

Motorised knapsack mistblowers.

46. These are used in most countries where tsetse control is practised. The model currently in use in Tanzania is the Motoblo Super 70[22] which closely resembles the Solo-Port 430[23]. Both are equipped with 70 cc two-stroke engines, and 10 l insecticide tanks.

22 Kent Engineering and Foundry Ltd. Tovil, Maidstone, Kent, United Kingdom.

23 Solo Kleinmotoren GMBH, 7034 Maichingen bei Stuttgart, Postfach 20, W.

Motoblo sprayers have been used in Tanzania since the early 1960's (21). Both the 60 and 90 models were also in use in Nigeria at about the same time. The model 60 was preferred to the latter because it was lighter and easier to handle. Further spraying operations with these machines have been described (77,99) but they have since been replaced by the CP 40[24], which is now out of production.

47. In spite of its smaller and somewhat unreliable engine, the CP 40 proved to be a reasonably effective machine. The plastic insecticide tank has a capacity of 10 l and in Nigeria it proved effective for spraying persistent insecticides in swamp forest (66).

A number of modifications were made to the C P 40, the most important being the replacement of the thin plastic air-hose with a fabric-coated rubber hose, due to the plastic hose being very prone to perforation by thorns. This resulted in appreciable air loss and a consequent decline in the spray penetration.

48. Three KWH 77[25] machines were used in Uganda, and they have been employed extensively elsewhere (67,100). Motorised knapsack mistblowers have also been employed in Rhodesia (32, 90) but how long they have remained in service is not known.

Centrifugal energy equipment

49. The only record of equipment of this type used in control operations (93) refers to the MEG[26]. Briefly this consists of a large centrifugal fan, powered by a 420 cc air-cooled 4-stroke engine. At the exit of the fan housing there is an aerofoil section containing a propellor which, powered by the air flow, rotates a wire cage at speeds of up to 20,000 rpm. Insecticide is fed into this cage through a nozzle and is emitted as small droplets which are carried away in the air blast.

50. Another type, the ULVA[27] is a light-weight portable rotary atomiser. Insecticide is gravity fed to a nozzle in the centre of an atomizer consisting of two stacked corrugated plastic discs with serrated edges. These are rotated at speeds of up to [illegible] rpm by a small 7 watt electric motor, powered by a 12

24 Cooper Pegler Ltd., Coopers Hill, Sussex, RH15 9LA, United Kingdom
25 KWH Nevelwin Holland BV, Wadenoijen-2720, Postbus 47, Bommelweg 63.
26 Micron Sprayers Limited - Out of production.
27 Micron Sprayers Ltd., Three Mills, Bromyard, Herefordshire, United Kingdom

volt battery. Extensive use is being made of the ULVA in crop protection work in the tropics and in Nigeria it has been used to apply ULV formulations.

Smoke generators

51. Some small scale control operations were carried out with smoke generators against G. palpalis (G. fuscipes) in Uganda (20,47), but accurate dispersal of smoke under varying weather conditions was difficult. Efforts have been made to overcome these problems but this technique has not been used extensively.

Thermal foggers.

52. Field trials with the Todd Insecticidal Fog Applicator[28] (TIFA), and its use in the treatment of small pockets of tsetse have been reported (36, 47, 94). The Swingfog[29] has also been used (22, 23, 31, 62), and larger versions of this machine such as the SWI00[30] are available for vehicle mounting.

Aerosol dispensers

53. A problem in any tsetse control operation is the prevention of re-infestation and an essential aspect of protective measures is the deflying of traffic by pickets. Tsetse flies which are carried by pedestrians, cyclists and private cars can be caught with nets but this method is impractical for dealing with numerous flies which can be carried by a single lorry. In Uganda, small hand-operated sprayers are issued to pickets and both gaseous and hydraulic energy models have been tried. The former, which are invariably cheap, insubstantial and intended for household use, are uneconomic because of their short working life and inefficient because of the wide variation of droplet sizes produced.

Good quality hydraulic energy models such as the 2180[31] are more satisfactory. These are intended for indoor use, but could be used in garage-type buildings erected at road pickets where lorries are treated.

28 Tifa Limited, Cook Lubbock House, Waterside, Maidstone, Kent, United Kingdom
29,30 Jaydon Engineering Co Ltd. Beacon House, 28 Worple Rd, London SW19 4EE.
31 Ernest H. Hill Ltd, Beta Works, Fitzwilliam Street, Sheffield, United Kingdom

Selection of equipment

54. The diversity of types of spraying machines utilised in tsetse eradication work is largely attributable to the diversity of habitats occupied, not just by the genus as a whole but by individual species. Ground spraying techniques have also been developed more or less independently in the countries where control is practised in a variety of ecological circumstances. Consequently a variety of local factors have influenced the choice of equipment. The selection of machines is related to their spraying efficiency, cost, ease of handling, mechanical reliability, maintenance and availability of spares. Although tsetse control organisations carry out trials with different insecticides or formulations there is rarely any mention of comparative trials of different spraying machines.

55. Similar savanna woodland habitats of G. morsitans have been treated with spray guns and pressure retaining compression sprayers in Uganda and by motorised knapsack mistblowers in Tanzania. In Uganda, persistent insecticides have been successfully applied in tsetse resting sites with a 700 spray gun. When treating savanna woodland and forest communities where the undergrowth is not too dense to pass on foot, or where access could be provided with a minimum of path cutting, a compression sprayer (preferably a pressure-retaining type) adapted for use with a spray gun has proved to be most practical. A pressure control valve is fitted to ensure even emission and this is suitable for spraying trunks up to 3.5 m in height from a distance of 4 m. A much greater reach is often necessary when treating G. fuscipes infested vegetation from a boat. In such circumstances, a compression sprayer is inadequate but a small portable, engine-driven, high pressure diaphragm pump is used. With a motorised pump it is also possible to use an insecticide container with a much larger capacity than a compression sprayer, and this reduces refilling time to a minimum.

56. When dealing with thicketed or swamp forest habitats, access lanes are a costly item. Costs can be reduced by using suitable spray jets or motorised mistblowers which give better penetration in these situations.

AERIAL APPLICATION EQUIPMENT

Background

57. The use of insecticides has for some time been the accepted and main method of controlling tsetse flies and this is likely to remain so in the foreseeable future. Residual treatments of persistent insecticides (e.g. DDT and dieldrin) have been used both selectively and discriminatively by ground spraying methods. However, airspraying techniques have developed appreciably over the last few years, certainly to an extent where the use of aircraft to apply insecticides in anti-tsetse operations has progressed beyond the experimental stage. As far as the future is concerned, it seems likely that emphasis will be placed on the use of aircraft in many areas which are infested with flies and it seems probable that any large scale control programmes will contain a significantly large aerial input.

58. The principle reason for the choice of aircraft is the relative ease with which large scale operations can be carried out in comparison to spraying from the ground and also fewer trained staff required. Aircraft are able to apply spray to tsetse habitats which are inaccessible from the ground and this either takes the form of placing the residual deposits in specific sites or by space spraying a wide area. Aerial applications of insecticides are likely to produce more general environmental contamination than ground spraying, except that much lower dosage rates are used, and therefore it is essential to incorporate ambient pesticide monitoring in any operational airspraying programme (para. 4).

59. Application techniques by fixed wing aircraft and helicopters have now reached the stage of development such that suitable equipment is available to meet most tsetse control requirements. Many large scale programmes to control tsetse flies are now based on aerial application of insecticides and although they often involve a high financial commitment aerial spraying may be less expensive than ground spraying in terms of unit area covered, depending on the insecticide selected and the amount of ground per unit area. This is partly accounted for by the need for fewer personnel and less logistic support in aerial operations than ground spraying and this often simplifies the operational planning. However, there are often difficulties in executing airspray operations because of the necessity to service and repair sophisticated equipment in remote areas and to adhere strictly to a schedule of sequential applications.

The development of airspraying techniques

60. Research on application of insecticides from aircraft for tsetse control has progressed by two distinct and different methods. These methods are here referred to as "non-residual treatments" and "residual treatments". Although the use of aircraft in agriculture had its beginnings more than 50 years ago (1), for tsetse control, non-residual airspray treatments have been in use for almost 30 years and residual airspraying about 8 years.

Non-residual treatments rely on sequential applications of very small droplets of a relatively concentrated insecticide, dispersed widely in savanna woodland areas with the objective of applying spray droplets which will come into contact with tsetse flies either in flight or in their resting sites (45). This method has been used extensively in Eastern, Central and Southern Africa. Residual spraying treatments from aircraft have been developed as an extension to the traditional ground techniques and adapted to aerial spraying of persistent insecticides to specific targets where tsetse are known to rest. These have been particularly suited to tsetse control in riverine vegetation, ecotones and drainage lines in West African conditions, especially where the tsetse habitat is restricted during the dry season.

Non-residual spraying techniques.

61. Aerial operations to control tsetse fly began shortly after the second world war in South Africa, where Anson aircraft were fitted with extension tubes attached to their exhaust stubs. These devices were used to apply 5% solutions of DDT (102) to fly infested regions of Zululand. At about the same time in East Africa, work commenced on experimental programme of aerial spraying to study methods of controlling tsetse fly (para 2). Work was carried out on an experimental basis and involved studies of insecticide formulations and spraying techniques with supporting physiochemical and biological assessments. Early experiments were carried out with war service aircraft fitted with crude devices e.g. open pipes and thermal exhaust units which were used for the production of fine sprays and coarse aerosols (52,53,54).

62. Trials were ineffective in achieving control of fly but research continued throughout the years in improving application techniques, spray dispersal equipment

and insecticide formulations. Eventually improved fly control was achieved, but only at high costs (56). The development of an improved thermal exhaust device fitted to a Cessna 182 aircraft which was capable of producing good aerosol characteristics (70) was used to apply dieldrin and isobenzan (17) which gave very satisfactory control of tsetse flies at reduced cost. In 1964, endosulfan was introduced for the first time and this experiment was shown to reduce costs appreciably (51).

63. These experiments pioneered the use of aircraft for the control of tsetse flies by non-residual spray methods and laid down the foundation of techniques which have developed over the last few years in Central and Southern Africa. In 1967, an airspray experiment was carried out to control tsetse fly in SW Barotseland and this subsequently led to the commencement of a large scale spraying operation which was carried out the following year and covered an area of 1600 km^2 (81). The techniques have been further refined in Botswana in 1973 where a twin-engine Piper Aztec aircraft fitted with a single Micronair unit has been used to control fly in the Okavango Delta (61, 71)

Residual spraying techniques.

64. Trials were carried out in Kenya (4 , 72) using an experimental formulation of dieldrin applied by helicopter (Bell 47G) and fixed-wing aircraft (Piper Pawnee 235) to control G. pallidipes. The insecticide was formulated as an invert emulsion and was applied from a Bi- Flon[32] device. Spraying by helicopter proved to be prohibitive because of the high operational cost but trials were continued using a fixed-wing aircraft. The insecticide applied by this method was shown to penetrate the canopy and produce toxic deposits in the understorey thicket. A spraying technique was developed which consisted of applying a swath at intervals of 54m across the thicket and this proved to be effective in controlling fly for at least 8 months.

65. In West Africa, DDT, dieldrin and HCH as emulsion concentrate formulations have been applied primarily to clear riverine vegetation of G. tachinoides (92). Two applications at three weekly intervals were made from a Bell Helicopter

32 Shell International Chemical Co Ltd., London, England.

(47G-4A 280 HP) fitted with boom and nozzle equipment (33, 34). These areas have remained fly free for over 4 years. In 1971, discriminative spraying of dieldrin to vegetation usually sprayed from the ground was carried out in the Northern Guinea Savanna Zone (NGSZ) of Nigeria (91). The area sprayed consisted of riverine vegetation, Isoberlinia woodland and ecotones around hills and in the sub-plains (74). A 20% dieldrin EC was applied at the rate of 1.5 to 2.0 kg/ha and, with isolated exceptions where fly pockets were missed, these areas have remained fly free for over 3 years. During 1972 spraying trials in the NGSZ, a helicopter fitted with boom and nozzle equipment was successful in controlling G. morsitans for several months using ULV formulations at 0.5 kg/ha and 1.5 kg/ha of dieldrin and endosulfan respectively. Subsequently trials using eight Ulva[35] electrically operated rotary atomisers mounted on the boom of the helicopter indicated that fly was controlled and exterminated at 0.64 Kg/ha and 0.8 kg/ha with ULV formulations of dieldrin and endosulfan respectively to about 10% of the infested area (25).

Equipment for non-residual insecticide treatments

Open pipe

66. The first trials carried out in East Africa employed an Avro-Anson XIX aircraft fitted with four spray tanks having a total capacity of about 800 l. Spray liquid was emitted under gravity from two wide pipes which extended about 35 cm below the fuselage of the aircraft. Emission rate could be adjusted by an Iris diaphragm which was situated at the end of each pipe. Adjustments were made by the pilot on the cockpit during the flight and spray atomisation was achieved by the action of the slip stream which broke up the jet of liquid into spray droplets as it was emitted from the pipe. It was not surprising that the droplet spectrum from this rather crude device was fairly wide and the unit was subsequently discontinued.

33 Sorenson Aircraft Co., Box 264, Worthington, Minnesota, U.S.A.

34 Simplex Manufacturing Co., 5224 North/East 42nd Av., Portland Oregon 97218, U.S.A.

35 Micron Sprayers Ltd., Three Mills, Bromyard, Herefordshire, UK.

Thermal Exhaust.

67. One of the first devices to be used for the production of aerosol droplets was fitted to an Avro-Anson XIX aircraft (42). The coarse aerosol was produced by allowing the solution to flow into a modified exhaust system. The solution flowed through a narrow pipe 22mm internal diameter and into the exhaust pipe at a distance of 50 cm from the centre line of the exhaust manifold. It then passed down along the exhaust tubes 10 cm in diameter, and was finally emitted vertically downwards into the slip stream about 30 cm below the trailing edge of the wing. The installation was based upon a design used for similar work against tsetse flies in South Africa.

68. In 1962, research was reopened to develop thermal exhaust units for aerosol production to enable studies to continue on aerial applications of insecticides for tsetse control. A device was developed for a Cessna 182 and this consisted of an Inconel tube 45.7 cm in length and 74.6 mm in diameter which was secured to the exhaust stub of the aircraft (70). The spray liquid was fed into the exhaust extension through a metering jet located outside the exhaust system. Another device consisted of fitting extensions to twin exhaust pipes, the extensions being 2 slightly curved stainless steelpipes 5.1 cm in diameter and approximately 61 cm in length. A 340 l Sorenson[33] spray tank was fitted below the fuselage of the aircraft and the system incorporated a 3-bladed fan-driven Simplex[34] centrifugal pump (2.54 cm). The flow of liquid was controlled by two diaphragm check valves[36] each fitted with a strainer and a D4 orifice disc. The liquid then flowed through 2 copper tubes 0.32 cm internal diameter to the outlet ports of the extension pipes. The point of entry into the extension was 20 cm below the manifold, where the temperature was estimated to be 550°C. Thermal exhaust units are currently in use in Zambia with the parastatal organisation 'Rural Air Services' which has 3 Beechcraft 'Baron' twin-engined aircraft with Sorenson external tanks of 360 l capacity.

36 Spraying Systems Co. 3201 Ra Street, Bellwood, IL 60104, U.S.A.

Rotary atomisers (air driven).

69. Micronair[37] has produced a number of rotary atomisers over the last few years and these atomisers have been used on a variety of aircraft in numerous pest control operations throughout the world. The physical characteristics of the spray emitted from the rotary atomisers, are determined by the liquid throughput and the speed of rotation but the droplet spectrum achieved is more uniform than hydraulic spray nozzles. The units are driven by a 6-bladed windmill, whose blade angle and therefore speed of rotation can be adjusted between flights. Micronair equipment is used mainly for the ULV application of mists for the control of insects and diseases in crop protection and can be modified to produce aerosols in the range of 10-40 microns in diameter applied from small single-engined aircraft (69), provided that the insecticide solution is fairly volatile (para. 18). The latest unit to be manufactured in this series is the AU3000 Micronair rotary atomiser and this has recently undergone trials in Botswana fitted to twin engined aircraft to control tsetse fly. This has a smaller diameter cage (12.7 cm) than previous models and when fitted to a Piper Aztec spraying at a speed of 260 km/h gave droplets of approximately 25-30μ vmd using insecticide solutions containing diesoline and Shellsol AB (71).

Hydraulic Spray Nozzles.

70. In Tanzania, a Beagle Husky D5/180 single engined aircraft fitted with four nozzles has been used for tsetse control. The nozzles are located each lift strut and wing tip, and are fitted with D2/25 orifices and strainers. The total throughput is approximately 2.7 l/min, the reported droplet size 40-80μ and a swath width of 90m is employed for a spraying speed of 175 km/h. A 20% formulation of endosulfan in oil is used at a nominal dosage rate of 12 l/km^2.

37. Micronair (Aerial) Limited, Bembridge Fort, Sandown, Isle of Wight, UK.

In general these airspray operations have proved satisfactory but the very small pay load of the aircraft makes it difficult to treat large areas. Five applications are made at 3 weekly intervals. The aircraft is not fitted with an automatic navigation aid and therefore ground marking is vital. Unsatisfactory marking has led to errors in several instances and it is suggested that automatic navigational guidance systems would obviate many of these errors (para. 82).

71. In recent years, other types of atomizing devices have been investigated (84), but at present the rotary atomizer principle appears most suitable for non-residual insecticide application.

Equipment for residual insecticidal treatments

Bi-Flon apparatus

72. The Bi-Flon apparatus was designed specifically for the application of pesticides formulated as invert emulsions. Invert emulsions are produced when invert oils are mixed in water, the oil phase becomes continuous and the water phase dispersed. The greater ratio of water to oil, the more viscous the emulsion. The use of inverts was designed to develop drift free spraying but the equipment and the method proved to be too complicated, and the practice has now been discontinued. However, it is worthwhile mentioning some experiments which were carried out to control G. pallidipes and G. brevipalpis in the Lambwe Valley, Kenya, because it may well have a bearing on future spray programmes using residual insecticide formulations. Trials with a Bell 47G helicopter proved to be very effective in producing appreciable reductions in fly numbers but the technique was too expensive and investigations were not pursued further (72). Trials were continued with fixed wing aircraft and efforts to cut the cost of reducing both insecticide and spraying time were successful. Studies were made to evaluate the effect of spraying at intervals of 54m and it was shown that at least 60% of the area would have to be sprayed to achieve any satisfactory degree of fly control (4).

Boom and nozzle equipment.

73. Residual spraying has been carried out in West Africa where helicopters have been in use to apply persistent deposits from the air in the Sudan savanna zone in Niger in 1969. An area mainly infested with G. tachinoides in dense riverine forest were sprayed twice with mixtures of DDT, dieldrin and BHC in an emulsion concentrate using a Bell helicopter 47G-4A fitted with boom and nozzle equipment. In 1971, a trial covering 240 km^2 in the NGSZ in Nigeria was carried out with the same helicopter fitted with two spray tanks, each of 100 l capacity fixed to the right and left sides of the engine. A rotary pump which was belt-driven from the engine was employed with 32 D3/25 nozzles at intervals of 50 cm. Applications were made at speeds of 32-40 km/h spraying to within 1-2 m of the canopy and this gave an effective swath of about 20 m. In larger broken areas of Isoberlinia woodland, swaths were sprayed at intervals of 200 m. Only about 10% of the area was treated according to the discriminative ground spraying technique developed earlier for ground spraying (74). Dosage rates were reduced and techniques improved, and this was achieved by using fewer nozzles on the boom, thereby reducing the liquid throughput. In 1972, 12 of these nozzles were used to apply a ULV formulation of endosulfan in a vegetable oil. This ULV technique enabled helicopter applications to be made more efficiently in terms of insecticide used, and in the overall cost of the operation.

Rotary atomisers (electrically powered)

74. During the period 1972-73, spraying techniques in Northern Nigeria were further refined by employing modified Ulva atomisers and 8 of these units to a Bell 47G helicopter. Three were fitted on each side of the boom and two behind the engine. Each atomiser was driven by a 24 volt motor and rotated at a speed of 9000 rpm. Liquid was carried from the boom through a restrictor to the atomisers and a constant flow was achieved. The system allowed for multiple and single operation of the atomisers during the flight and the spray techniques employed were similar to those used in earlier trials. The helicopter flew at 25-32 km/h over dense riverine vegetation and 40-47 km/h over open Isoberlinia woodland where spray swaths were made at intervals of 200 m.

75. In 1973, an investigation was carried out to study the penetration of spray droplets when applied from electrically operated rotary atomisers fitted to a helicopter to a forest habitat in Ivory Coast (60). A Bell 47G-4A 280 HP was used for the trials and carried 2 tanks, each 100 l, fixed to right and left sides of the engine. The rotary pump, driven by a belt from the engine, supplied the spray system with liquid. The system consisted of 8 electrically driven prototype Ulva atomisers, which could be individually activated. These were attached at intervals of 0.5 m along a centre and two outer booms having a combined span of 10.5 m. The 24V/60W atomiser motors gave a nominal rotation speed of 9000 rpm unloaded. Spray droplet sizes depended on throughput and this could be altered by changing the size and number of the liquid feed nozzles.

76. Experiments have also been carried out to study the effectiveness of several ULV insecticides applied by helicopters to control G. palpalis gambiensis and G. tachinoides in the area of the WHO Onchocerciasis Control Programme in the Volta River Basin (24). The helicopter used was a Bell 47G-4A, 305 HP with a speed range of 32-80 km/h and two rotary atomisers secured 6-8 m apart were used to apply ULV insecticide formulations. Two types were used: 1 type produced droplets between 20 and 30 μ in diameter which were applied at a rate of 0.6 l/min; the other type, which had large apertures, produced droplets of 80-100 μ diameter at 1.2 l/min. The helicopter flew at a constant height about 2 m above the canopy; but it was necessary for it to make side turns to follow the bends in the water course. The powerful air current propelled downwards and backwards by the rotor carried the insecticide, which assisted the penetration of spray into the vegetation at ground level. In order to avoid losses due to convection near the surface of the ground, ULV applications were conducted for about 2 hours after sunrise

Types of aircraft suitable for anti-tsetse operations

77. Small single engine fixed wing aircraft are of limited use in tsetse control operations except possibly in the carrying out of experiments, where relatively small areas need to be treated. In most instances, aircraft below 2500 kg maximum take-off weight would not have the range or weight carrying capability required for such programmes. It is probable that no single type of aircraft

would be suitable for large scale tsetse control programmes and especially if a range of different tsetse habitats require treating. Large, flat areas can be satisfactorily sprayed with medium and possibly large multi-engined aircraft while small mountainous areas, often found in Eastern Africa, are probably more suitably treated by light-twin or medium-single engined aircraft. Mountainous areas, areas difficult of access and especially winding riverine habitats are treated more effectively by a light helicopter.

78. In general, the smaller types of fixed wing aircraft used in tsetse control operations should have good pay load and range characteristics, be easy to control at low flying speeds and have good short take-off and landing (STOL) characteristics. In addition, they should allow the pilot good forward and downward visibility and be corrosion proofed against the effects of insecticide chemicals. Tsetse control operations are often carried out in remote wooded areas where the opportunities for making a safe emergency landing (e.g. in the event of engine failure) are limited. For this reason, multi-engined aircraft should be used whenever possible. Twin engined, aircraft should have a satisfactory single engine performance at maximum take-off weight up to 2500 m density altitude.

79. With helicopters important considerations are the forward and downward visibility for the pilot and the manoeuverability of the aircraft. The helicopter may be required to land in unprepared areas and a shielded tail rotor and high lift skids are valuable features. Any type of helicopter can be used in tsetse control operations although machines with a maximum take-off weight in excess of 1500 kg will probably be prohibitively expensive to operate.

80. Despite rising prices which have recently affected all aspects of pest control throughout the world, airspraying costs for tsetse control have actually decreased since techniques were first developed. This is attributed to a number of things but primarily, spraying equipment design, better insecticides and improved application techniques have all played a major role in reducing costs. Improvements in dispersal equipment have resulted in more efficient spray atomination which, as a consequence, has helped develop application techniques.

Aircraft utilisation has increased as a result of extending swathe widths and high spraying speeds. Costs have also been reduced because of better pesticides which have been discovered and formulated as concentrates in aromatic oils containing higher percentages of active ingredient than was possible when field trials were initiated.

81. At periods of peak demand the work output of aircraft can be extended by the employment of additional pilots over a 7 day working week, or by fitting high powered lights in the nose and on the wings of the aircraft which makes it possible to fly at night. Typical work output data have been derived for various types of aircraft which are or may be used in tsetse control programmes (83).

Navigation aids

82. No ground markers are needed for helicopters in West Africa when treating tsetse in areas such as clearly visible drainage lines and vegetation inter-zones. However, traditional methods of swath marking for aerial spraying in tsetse control operations over large woodland areas have been in use for some time e.g. smoke fires, flags, balloons, marker bands, signal flares or lights. The development of tsetse control techniques using fast aircraft, flying longer spray runs, wider swaths and night flying has made the development of more sophisticated navigational aids desirable. Several types of airborne guidance systems are under investigation:-

- One system is based on an airborne phase measuring device which measures the phase difference between the radio emissions from two or more ground stations (106). The equipment is essentially a refinement of the Decca Navigation aircraft guidance system and has the disadvantage that ground transmitting stations are required, sited at accurately mapped locations. Although easily portable ground stations are now available, these may be difficult to site correctly in remote areas.

- Another system consists of a sensor unit which measures the inertia changes induced by attitude and acceleration changes in the aircraft during flight. The inertial navigation systems (INS) is entirely self-contained within the aircraft and no ground stations are required (7). The main disadvantage of INS in vector control operations using light aircraft is the cost and weight of the equipment,

and the fact that the system is difficult to adjust to flying reciprocal tracks.

- . Medium and larger types of aircraft can be fitted with highly accurate electronic navigation equipment (e.g. Doppler, VLF) but ground markers are required to line up on approach and exit from large blocks, especially when spray runs are many kilometers in length. In addition, these aircraft may be equipped with instruments to allow flying at night within close proximity to the woodland canopy. As weather conditions at night are often suitable for insecticide applications from aircraft, nocturnal tsetse control operations have been studied (61,71).

PART II. FUTURE REQUIREMENTS FOR INSECTICIDES AND APPLICATION EQUIPMENT

INSECTICIDES

1. Candidate compounds for tsetse control from commercial companies, research institutes and other sources should continue to be assessed for insecticidal activity in laboratory tests as a basis for selection for field evaluation. This selection should take into consideration not only toxicity to tsetse flies but also existence of a suitable formulation, availability and cost, toxicology and possible effects on non-target organisms. Some of these factors are listed (Appendix I) for new compounds already regarded as possible replacement chemicals on the basis of toxicity to flies. The availabilities mentioned are of the order of 1g to 100g for laboratory testing, 1 kg to 100 kg for field trials, and in normal commercial quantities for those which are readily available, and apply to the situation as far as it is known at the present time.

2. Highest priority should be given to field evaluation of the synthetic pyrethroids, NRDC 143 and NRDC 161, which are outstanding in their toxicity to tsetse flies and their persistence in spray residues and could be used in both aerial and ground sprays. NRDC 161 is the most potent insecticide known against many insects but also has a high mammalian toxicity with a site of action which differs from other pyrethroids. It is important therefore that further information should be obtained as soon as possible on hazards to other animals although it should also be noted that the very powerful insecticidal action means that it can be used at lower concentrations and dosages than the other candidates.

3. The organophosphorus compounds and carbamates listed have good to moderate toxicities to the flies, as measured by topical application, and can be divided into those which are likely to have a short term persistence only (for example, fenthion, naled, bromophos, propoxur) and those which could have a longer residual action (for example, azamethiphos, tetrachlorvinphos, jodfenphos, bendiocarb). Bromophos from the former group and tetrachlorvinphos from the latter have already been examined in field trials and found to be not very promising.

4. The susceptibility of different species and strains of tsetse to endosulfan and dieldrin and to representatives of other chemical classes that are likely to be used in field operations should be measured in different parts of Africa. This will provide guidance for variations in dosages required and also base-line data for a systematic monitoring programme for resistance. A simple standard method should be adopted; the most suitable is probably the WHO method for topical application (111), but field performance should also be studied by methods utilising tarsal contact with weathered deposits on sprayed surfaces (e.g. bark) if persistence is to be investigated.

Residual applications to vegetation at high volume rates

5. Solutions are not usually employed because the solvent is expensive compared with water but they were used in early trials in East Africa with DDT (95)or more recently in Nigeria with dieldrin (73). The cheaper solvents such as kerosene which can be used at high volumes evaporate rapidly from deposits and do not influence persistence or activity of the insecticide by their presence. They can modify the initial distribution of insecticide by moving it into bark or leaves before they evaporate.

6. Emulsions or suspensions are much commoner systems for insecticide dispersal and the two insecticides DDT and dieldrin are invariably used in these forms in the larger control schemes; for example in Nigeria, Uganda, Tanzania, Kenya and Zambia. Suspensions are prepared from water-dispersible powders which contain insecticide and inert diluent particles and surfactants and give dry deposits since the water evaporates very rapidly. Biological potency depends upon the particle size distribution of the active ingredient/and its physical state the surface which has been treated (44). Finer particles are picked-up more readily by resting insects while the adhesive properties of surfactant residues reduce pick-up on the less porous surfaces. Those powders which meet WHO specifications have about the optimum particles size distribution.

7. Since the insecticide is in solution in emulsion concentrates, or in the emulsions prepared from these, the physical forms of the deposit after solvent and water have evaporated will be controlled by the crystallization properties of the insecticide and, again, the sprayed surface since this crystallisation

occurs more readily on some surfaces than others. (5).

8. The persistence of the deposits resulting from the use of powders or emulsions will be controlled by the physical properties of the active material (e.g. dieldrin is more volatile than DDT), by climatic variables and by the surface sprayed. Thus water-dispersible powder deposits have been found more effective in hot, drier areas than those from emulsions but the reverse is true in cooler areas with higher rainfall (63,76). The powder residues are more easily washed away by rain than those from emulsions. Another important factor is the intrinsic toxicity of a compound to the flies. For example dieldrin is more potent than DDT and deposits can be reduced by a larger amount but still be more effective.

9. All the candidates for replacement insecticides in tsetse control are available, or could be made available, as water-dispersible powders and emulsion concentrates. A few, such as pirimetaphos, azamethiphos, tetrachlorvinphos and bendiocarb, have a low solubility in the common solvents used to prepare emulsion concentrates but this could be improved with known co-solvents. Conversely their low solubilities mean that they usually make good water-dispersible powders.

Aerial application at ultra-low volume rates

10. This usually requires that the formulation should be a solution of high concentration, say 10% upwards, since it is important that a lethal dose is present in one or very few droplets. Although this criterion applies to most insecticides it is possible that with exceptionally toxic compounds such as NRDC 161 the concentration can be reduced to something of the order of 1%. For these solutions the vital component is the solvent or, more often, solvents. Their properties control the initial atomization, the reduction in droplet size during passage to the target and the efficiency with which the insecticide passes into the insect either from droplets on the cuticle or from droplets on surfaces on which the insect rests. They can also influence the persistence of insecticides in spray deposits when they are of low volatility themselves.

11. A discussion of all these interactions between insecticide, solvent,

insect and surface would be too long for this report. Briefly, however, the best solvent system probably consists of a non-volatile component such as a vegetable oil, plasticizing ester or Dutrex-type petroleum extract combined with a volatile solvent which may be lost during application but ensures that the physical properties of the blend are appropriate for the atomization process. The non-volatile solvent is a less efficient carrier for insecticide through the cuticle if a droplet lands on the insect itself but can multiply the life of the active ingredient in a residue by several times by reducing its volatility.

12. There are likely to be difficulties in preparing high concentrations of some of the newer compounds because of their low solubility in many of the common solvents. The organo-chlorine compounds as a group are reasonably soluble in petroleum-derived solvents or in aromatic solvents from other sources. Some organo-phosphorus esters also have high solubilities (bromophos and jodfenphos) or are miscible (chlorfenvinphos and fenthion) but others, especially the phosphates are very poorly soluble in the usual solvents. Pyrethroids are usually readily dissolved but the difficulty of low solubility is again encountered with most carbamates. These and the phosphates can only be dissolved in water-miscible, hydrogen-bonding solvents such as dimethylformamide, N-methyl-2-pyrrolidone or hexamethylphosphoramide. Each of these has been used as a solvent or co-solvent in commercial ULV solutions. Unfortunately they are also good solvents for many polymers used in the hoses and washers of spray gear and their water miscibility means that insecticides can come out of solution if water is used for washing the equipment. They are also relatively volatile and are likely to be lost during or immediately after application and may have undesirable attributes since they facilitate skin absorption of toxic chemicals. It will be seen that the formulation of many of the newer insecticides will need to be considered with more attention to solvent properties than was necessary with the compounds used previously.

13. Other types of formulation have been tried or may be considered in the future. The relatively insoluble insecticides are easily milled to give fine suspensions in water, the 'col' types, or in non-volatile oils as, for example, the early DDT-spindle oil or carbaryl-oil mixes. These can be sprayed as supplied

or diluted to suitable concentrations with water or oil respectively. Inverted emulsions have been tried in Kenya (72) but special spray equipment is needed to form these. Micro-encapsulated insecticides may have a place in tsetse control although they are likely to be more expensive than most other formulations. They would be most useful in extending the lives of those insecticides which are promising in other respects but lack persistence and would therefore need to be designed with suitable leaching or disintegration rates.

GROUND EQUIPMENT

14. Spraying machinery manufacturers are dependant to a large extent on requirements of the agricultural market although it has been possible in some areas to utilise locally made machinery, provided that it conforms to accepted standards (79) and is sufficiently cheap. It is probable that any machines developed for anti-tsetse operations will also have to have suitable outlets in crop protection situations if production of equipment is to be economically viable. Some manufacturers would be willing to make modifications of existing equipment for tsetse control provided that some commercial return was evident.

15. Developments in ground equipment are proposed in the following areas:

Hydraulic energy equipment

Spray lances.

16. Shut-off valves should be made simpler and more reliable, possibly making greater use of plastic to reduce corrosion problems. Lance extensions are required which can quickly and easily be fitted to existing lances to extend their range of operation. Bayonet type attachments should be used wherever possible.

Spray guns.

17. Tsetse flies are found in many different types of plant community and equipment is needed to treat a wide variety of preferred resting sites. Control of liquid pressure and spray pattern shape is essential and although some work has been done to investigate spray guns giving varying pattern widths, this needs to be developed further. A device which can alter the spray width

should be capable of being operated by the hand holding the lance

Pressure retaining sprayers.

18. Pressure retaining equipment is urgently required to replace equipment used in the past but which is no longer available (para 33). Good compression sprayers should have the following specifications:

- Tanks to be made of suitable gauge of stainless steel or plastic with a holding capacity of 15-20 l.

- Operating pressure range of 6-3 kg/cm^2, or even higher a pressure gauge to be fitted to the top of the tank, and a pressure regulating valve.

- A shut-off valve of the floating ball type should be used.

- Capable of being filled with air and insecticide with its own detachable pump and with a separate change pump.

- Fitted with an on/off cock on the insecticide outlet pipe.

Hand compression sprayers.

19. Hand compression sprayers which meet the WHO specification (30) should be tested to determine their suitability for tsetse control.

Lever Operated sprayer.

20. No requirement for this type of equipment is anticipated.

Motorised machines

21. Any machine which is operated by means of an engine will present maintenance, servicing and repair problems in the field. Nevertheless, some requirement is seen for this type of machine.

Motorised knapsack mistblowers

22. This type of machine is most useful in areas where insecticides must be applied to dense vegetation and, where access by the sprayman may be difficult. There is a wide variety of motorised knapsack mistblowers available and these should be inspected to determine which are most suitable in specific situations (para 46-48).

Vehicle mounted machines.

23. No requirement is seen for this type with the exception of fogging and ULV apparatus attached to or mounted on vehicles. The use of this equipment would however be limited to areas accessible to vehicles and with suitable ambient weather conditions.

Fogging machines.

24. These machines have found little use in tsetse control operations. Their use would in any event be restricted by weather conditions. Nevertheless there are situations, such as when dealing with tsetse living in scattered and relatively small thickets among cultivation, where a non-persistant insecticide might have to be employed and a small portable fogger might be the most convenient equipment to use. The great advantage of this type over ULV equipment is the visibility of the insecticide after emission.

Manual aerosol producers.

25. There will always be a need at pickets for such equipment, for eliminating tsetse being carried by vehicles. A wide variety of sizes and qualities of both gaseous and hydraulic energy hand-sprayers are available, but few are large enough or sufficiently robust to stand up to extended daily use.

AERIAL EQUIPMENT

Requirements for airspraying equipment

26. The need to produce aerosol droplets (vmd 20-50 um) for sequential non-residual applications of insecticides for tsetse fly control has been well known for a considerable time, but there has been little incentive for spraying machinery manufacturers to invest in research to produce new apparatus. This is understandable because such ventures could show little returns since there is only likely to be a demand for a small number of units. However, of late there has been an increasing awareness of the need to produce ULV and fine spray dispersal equipment for crop protection purposes and therefore, there has been an increasing number of prototype rotary atomisers available of very variable performance. Most of the units now at the prototype stage are

electrically powered and some of these have already been used and assessed for tsetse control operations. However there is still a need for a robust and reliable unit capable of producing small aerosol droplets for use on both helicopters and fixed wing aircraft and further work in this area is recommended. As far as small fixed wing aircraft are concerned thermal exhaust units appear to be the most suitable equipment for aerosol production although the droplets produced are very variable in size and some of the larger droplets are deposited at ground level near the source of emission.

27. On faster medium sized fixed wing aircraft which are capable of spraying at speeds of approximately 260km/h wind-driven rotary atomisers have been produced which are suitable for the production of aerosol droplets for non-residual tsetse control both with volatile and partially volatile insecticide formulations. The size of the units used in recent experiments is significantly less than older units but, despite their smaller size, the combination of increased rotational speed and increased flying speed has given better atomisation of spray droplets and droplet sizes of 25-30 microns vmd/ have been obtained. The performance of electrically operated rotary atomisers has not been assessed on fixed wing aircraft for tsetse control but this is an area worthy of further study because these units may prove suitable for aerosol production, provided they are sufficiently robust for field use; the use of suitable hydraulic spray nozzles should also be studied for aerosol production on faster aircraft.

28. Equipment for residual applications will continue to be required where persistent insecticides are applied by helicopter with boom and nozzle devices when supplying sprays of emulsion concentrate and dispersable powders. Equipment for making ULV insecticide application will necessitate the use of electrically powered devices; especially with the need to control the droplet size of the emission and the placement of the sprays in specific targets, e.g. along riverine areas and ecotones.

29. There is a need to continue with research into the development of residual spray application technology using fixed wing aircraft. This may be required if an environmentally satisfactory residual insecticide is discovered. In this event, there would be a need to review the strategy of current control techniques although this would not necessarily require the development of new items of

equipment. Conventional boom and nozzle and rotary atomisers would be suitable but field techniques would have to be studied in order to apply the insecticides in the most efficient manner.

30. Further development of track guidance systems is essential to improve reliability, accuracy and ease of operation in large-scale tsetse control schemes using aircraft.

PART III. RESEARCH TO IMPROVE THE TECHNOLOGY OF TSETSE CONTROL

THE STATUS OF TSETSE CONTROL USING PESTICIDES

1. Control or extermination of tsetse flies by chemical means must show some advantage in cost, speed of action or in environmental impact over other methods of control, e.g. total or partial bush clearing, to be an economic proposition. Sufficient isolation of tsetse habitats is necessary if permanent eradication is to be sustained since applications of insecticide do not themselves change the habitat. This of course is not necessary if only short term reduction in tsetse numbers is required as for example to abate a sleeping sickness epidemic but where a land utilisation programme which includes a livestock component is in progress and settlement of people is taking place, eradication of fly is usually necessary.

2. Two basic approaches, involving the use of insecticides, have been proven as capable of eradicating tsetse flies. One involves a single (occasionally repetitive) relatively heavy deposit, applied in a discriminative manner either by ground-spray teams or from the air, and the other involves repeated low dose applications from the air of non-residual insecticide which kill all the adult population present at the time of application. The choice of method will depend on a variety of circumstances, including the climate of the area, its topography and the degree to which the tsetse population may be seasonally restricted to specialised habitats occupying only a small proportion of the total area infested at more favourable seasons.

Ecological considerations

3. Tsetse eradication operations having the objective of facilitating the development of a balanced and mixed rural economy will only achieve their objective if executed on a substantial scale. This means taking the boundary of the operational area to the limit of the infestation or to perimeters which can easily be defended, where the cost of the defence action is small in relation to the area reclaimed from infestation and the extent of land resource freed for development.

with current and future community needs without having to ensure that no environmental circumstances exist in the project area which can harbour infestations.

4. The attainment of the eradication objective means that the land resources can be exploited strictly according to their diverse capabilities and the need of the community whilst retaining sufficient in reserve for future generations, for an adequate forest estate, for pastoral rangeland, for the conservation of erodable areas and for the preservation of wildlife. The difficulty which arises when "settlement" is used as a concept for consolidating land reclaimation against tsetse infestation is that the level of the land exploitation necessary to reduce infestations to a level where they no longer cause grave repercussions on livestock can not be attained without overburdening the land resource, cannot be supervised on the scale required and often does not fit in with community need and capability. Further, the trypanosomiasis problem will remain if an adequate proportion of the land resource remains uncultivated or is allocated to various and essential conservation objectives.

5. Thus the delineation of tsetse infestations and land resource surveys are essential precursors of tsetse eradication projects. Land use surveys incorporating current land use and land capability assessments relating to the development of the balanced and mixed rural economy essential to meet the needs of an expanding community with increasing living standards should proceed and provide the justification for large area tsetse eradication operations. They are a fundamental component of the field research effort required prior to the design and execution of substantial anti-tsetse activities.

Specific considerations

6. The natural limits of the tsetse population to be attacked should be determined before control operations are initiated. Surveys should be undertaken with care to determine population limits and maximum dispersal capabilities at the most favourable seasons of the year. Low density populations require the development of new sampling techniques (para 9).

of those plant communities with which a large proportion of the tsetse population is associated, especially at unfavourable seasons of the year ("discriminative" phase). Resting sites utilised by the flies, throughout the day and night, in these plant communities should be determined ("selective" phase). Resting sites can be confined to a small proportion of the overall habitat, and very restricted use of insecticide is possible under such circumstances, especially when applied by ground-spray teams applying the principles of "discrimination" and "selection". Findings from one area are not necessarily applicable elsewhere within the range of a species and such studies are necessary wherever control operations are to be undertaken.

8. Less detailed knowledge of the ecology of the species to be attacked is necessary when blanket applications of non-residual insecticide are to be employed. In order to determine the optimum number and interval between application it is, however, necessary to know the duration of the pupal period throughout the time when spraying is to be conducted; particular attention should be paid to the coolest breeding sites, where the period will be most prolonged. It is the maximum period and not the mean which is most significant. For the same reason, it is also necessary to determine the length of time between the emergence of a female fly and the production of its first larva throughout the spray period, particularly at the shortest period.

9. At the conclusion of control operations, detailed surveys are again required to determine whether or not eradication has been achieved. The detection of tsetse flies at very low population densities is difficult and inefficient and the development of appropriate methods is perhaps the most pressing need in studies of Glossina ecology. Now, efficient devices for sampling tsetse populations have been developed (104); the possibility of adapting these to detect low density populations requires urgent investigation.

Environmental effects

10. If land is to be opened up for the purpose of providing food resources, then it must be recognised that the agricultural activities themselves which will ensue will bring about a far greater environmental change than initial applications

of insecticides for tsetse control. Furthermore, the agricultural changes will require greater amounts of more persistent insecticides for crop protection than will be used in public health. Accordingly, planners of such large programmes should approach the problem of environmental modification from a realistic viewpoint. Governments which seek the long-term objective of increased agricultural yield cannot at the same time criticize too severely the short-term use of insecticides for vector control.

11. The alternatives to the use of insecticides for tsetse control are the direct killing of game and habitat clearance. The environmental effects of these operations are probably greater than the use of the insecticides. Although genetic control of Glossina is a distinct feasibility, a great deal of work will have to be done to determine its operational value. Despite recent publications on the possibilities of biological control of Glossina, it is considered to have a remote feasibility.

12. For tsetse control, certain areas of wooded savannah, riverine forests, and forests proper, including the ecotones between such systems, will be treated. The first step would be to map or classify the major ecosystems that will be covered by treatment, and based upon existing literature, to provide a preliminary listing and structure of the major animal groups in each. From this a series of indicator organisms can be derived and their availability and relative abundance in each of these main ecosystems approximated and checked by spot surveys. Once spraying operations have been decided upon, and the toxicity of the insecticide(s) selected determined for major groups, i.e. mammalian, avian, fish, etc., a sampling procedure for the indicator species population levels can be established. There are numerous adequate procedures for determining vertebrate population levels depending on availability of manpower and the precision desired. Other major groups to be sampled would be non-target forest insects as well as soil organisms, especially Annelida and arthropods.

13. Physical measurements to determine the distribution and quantity of insecticides applied by aerial spraying in sample habitats should also be made. Initially, this should be done in a wooded area at a canopy level, at inter-

mediate tree level, on ground vegetation, and ultimately in the soil. Again, details can be determined for each of the habitat types.

FUTURE RESEARCH REQUIREMENTS

14. Recent progress in the use of fixed and rotary wing aircraft and ground equipment for insecticide applications need to be exploited in a wider variety of situations and new insecticide formulations required field evaluation. Thus field studies to evaluate new techniques and chemicals should be extended to situations where treatments have been difficult or impossible in the past as in certain riverine, moist savanna and forest zones. In some situations where control has been successful alternative methods are desirable, as for example when economic or environmental aspects must be taken into account.

Laboratory evaluation of new insecticides and formulations

15. COPR is engaged in a continuing programme for the laboratory testing and evaluation of candidate insecticides for toxicity to tsetse flies in collaboration with WHO. Comparative toxicities of compounds supplied by industry, research institutes, universities and other sources are determined by a standard method of topical application of solutions to teneral G. austeni obtained from pupae*. The results are published from time to time (43) and indicate the most promising insecticides for space sprays. Other properties such as volatility, solubility and stability are also measured to indicate suitability of compounds for residual activity.

16. A research programme on formulations of insecticides for residual activity on vegetation is also currently in progress. A spray tower has been constructed for the simulation of ULV conditions; that is, the application of concentrated solutions of 10% or more active ingredient at low volume rates and controlled droplet size. Observations are made on the physical state of deposits on leaves, and of the persistence of the active ingredient on leaves. The persistence and availability of the active ingredient is measured by bioassay and chemically by GLC analysis.

* Supplied by Ministry of Overseas Development and University of Bristol, Tsetse Research Laboratory, Dept. of Veterinary Medicine, Langford House, Langford, Bristol, ES18 7DV, UK.

Field studies of new insecticides and techniques

Ground applications of residual insecticides.

17. Persistent chlorinated hydrocarbon insecticides e.g. DDT, dieldrin and HCH are in current use for tsetse fly control. Insecticides are applied selectively to the known resting sites of flies e.g. the trunks of trees and the undersides of certain branches or to leaves in the canopy, and are effective when applied to riverine and savanna vegetation using ground spraying machines. Insecticides which are environmentally more acceptable and less toxic to cattle and humans would be evaluated for use by this method. Trials with these insecticides should include dieldrin as a reference treatment. Details of proposed trials are shown in Appendix 2.

Ground applications of non-residual insecticides.

18. Hand carried equipment for applying aerosols for tsetse fly control has been used in various parts of Africa, but the method has never been developed to any extent. Equipment applying DDT as fogs has been tried but there is a need to evaluate alternative less persistent insecticides applied as ULV or as dilute formulations suitable for fogging. These methods are unlikely to lead to permanent eradication but there are requirements to reduce fly numbers rapidly in emergency sleeping sickness situations, in areas of human habitation or of tourist interest. It would be necessary to study sequential applications of insecticide if long term control was required. Applications of insecticide from boats would have to be considered for access to difficult riverine areas. Details are given in Appendix 3.

Rotary wing aircraft applications of residual insecticides

19. Persistent chlorinated hydrocarbon insecticides e.g. DDT, dieldrin and endosulfan have recently been shown to control tsetse flies effectively in West Africa by discriminative treatments of aerial sprays applied by helicopter to forest islands, drainage lines, ecotones and stretches of river where the vegetation is suitable. Since aerial applications are necessarily more diffuse [illegible] to evaluate alternative insecticides which are

environmentally safer and less toxic to man and cattle. It is also important to examine closely the economics of this method and the possibility of using different formulations for greater efficiency. Details are given in Appendix 4.

Rotary wing aircraft applications of non-residual insecticides

20. The control of tsetse flies along large stretches of rivers where ground access is difficult has always presented problems. Fixed wing aircraft do not have the manoeuverability to follow the course of the riverine vegetation and residual spraying from the air causes greater environmental side effects. There is therefore a need to devise a non-residual spraying technique using environmentally safer insecticides for the rapid reduction of fly, especially in areas where sleeping sickness is epidemic. Details are given in Appendix 5.

Medium fixed-wing aircraft applications of non-residual insecticides

21. The technique of applying aerosols from fixed wing aircraft for tsetse fly control has been well tried and has been shown to be effective with a variety of insecticides in field experiments and in large airspray operations but requires additional development work. Endosulfan is currently used at rates of 6-14 g/ha per treatment. There may be situations where this insecticide is a hazard, e.g. around rivers or lakes, and it would be worthwhile assessing alternative insecticides. Details are given in Appendix 6.

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Appendix 1. Properties of new compounds

Pyrethroids

NRDC 161 : Procida; low solubility in paraffinic solvents but unlikely to be formulation problems as it can be used at low concentrations; mammalian toxicity high and similar to dieldrin, AO rats 25-63 mg/kg; available for field trials.

permethrin (OMS-1021, NRDC 143) : Various licensees; generally high solubility so unlikely to be formulation difficulties; low mammalian toxicity, AO rats 1300 mg/kg; available for field trials.

Organophosphorus compounds

pirimetaphos (OMS-1504) : Sandoz; difficult to formulate as solution concentrates; low mammalian toxicity AO rats 1500 mg/kg; available for field trials.

azamethiphos (OMS-1825) : Ciba-Geigy; difficult to formulate as solution concentrates; low mammalian toxicity, AO rats 750-1400 mg/kg; available for field trials.

OMS-1283 (O-analogue of jodfenphos) : Ciba-Geigy; should be no formulation problems; moderate mammalian toxicity, AO rats 375 mg/kg; available for laboratory testing.

fenthion (OMS-2) : Bayer; no formulation problems; AO rats 215 mg/kg; readily available.

chlorfenvinphos (OMS-1321) : Shell; formulation problems unlikely; high mammalian toxicity, AO rats 12-56 mg/kg; readily available.

crotoxyphos (OMS-239) : Shell; formulation problems unlikely; moderate mammalian toxicity, AO rats 125 mg/kg; readily available.

phosmet (OMS-232) : Stauffer; formulation problems unlikely; moderate mammalian toxicity, AO rats 230-300 mg/kg; readily available.

dicrotophos : Shell; formulation problems unlikely; high mammalian toxicity, AO rats 16-20 mg/kg; readily available.

naled (OMS-75) : Chevron; would only be used as technical material for ULV applications; very volatile; low mammalian toxicity, AO rats 430 mg/kg; readily available.

tetrachlorvinphos (OMS-595) : Shell; difficult to formulate as solution concentrates; low mammalian toxicity, AO rats 2000 mg/kg; readily available.

bromophos (OMS-658) : Cela-Merck; no formulation problems; low mammalian toxicity, AO rats 2000 mg/kg; readily available.

jodfenphos (OMS-1211) : Ciba-Geigy; formulation problems unlikely; low mammalian toxicity, AO rats 2000 mg/kg; readily available.

carbamates

propoxur (OMS-33) : Bayer; may be some difficulty in formulating as high concentration solutions; moderate mammalian toxicity, AO rats 35-120 mg/kg; readily available.

bendiocarb (OMS-1394) : Fisons; difficult to formulate as concentrated solutions; moderate to high mammalian toxicity, AO rats 35-100 mg/kg; readily available.

Appendix 2. Ground applications of residual insecticides

Habitat	-	riverine gallery forest
Tsetse species	-	G. palpalis, G. tachinoides
Location	-	Nigeria
Insecticides	-	2 suitable insecticides; dieldrin as reference
Application equipment	-	hydraulic energy equipment; motorised knapsack mistblowers

Costs	$
1 x entomologist 6 m/m	14,000
1 x field officer 6 m/m	4,500
12 x fly boys 72 m/m	4,500
Insecticides (2 candidates, 1 standard)	1,000
Supporting services (land-rovers, drivers, equipment)	10,000
Total	34,000

A 12 man spray team should cover about 2-3 km per day. Each experiment area will be approximately 5 km in length. A 1 km chemical or physical barrier will separate each experimental area. Nigeria is a suitable site since collaboration must be sought with operational ground spraying teams which have been there for many years.

Costs as at June 1975.

Appendix 3. Ground applications of non-residual insecticides

Habitat	-	riverine
Main species	-	G. palpalis, G. tachinoides
Location	-	Nigeria
Insecticides	-	2 suitable non-persistent insecticides formulated in oils or as ULV
Application equipment	-	motorised knapsack mistblowers (modified for ULV application), fogging machines, manual aerosol producers

Costs	$
1 x entomologist 1½ m/m	4,000
1 x application expert 1½ m/m	4,100
Insecticides	500
Application equipment (machines + accessories)	1,000
Supporting services (transport lab. facilities, etc)	5,000
Local staff 9 m/m	4,000
Total	18,600

Effectively a short term exercise to evaluate the efficiency of single treatments of candidate insecticides. The need to collaborate with an international tsetse fly control unit is vital and they would provide supervisors, spraymen, fly boys etc. Approximately 2 km of riverine thicket will be used per insecticide treatment.

Costs at June 1975.

Appendix 4. Rotary wing aircraft applications of residual insecticides

Habitat	-	riverine
Main species	-	G. palpalis, G. tachinoides
Location	-	CCP area (November-April e.g. the dry season)
Insecticides	-	2 suitable insecticides, dieldrin as reference
Application equipment	-	Bell 47 G4 or 206A fitted with rotary atomisers

Costs		$
1 x entomologist 4 m/m		9,400
1 x application specialist, 1½ m/m		4,000
Insecticides		3,600
1 x field officer 4 m/m		3,000
[illegible] fly boys 48 m/m		3,000
Supporting services 13 DN/m		11,050
Helicopter 65 hours (@ $1,200 per hour)		78,000
	Total	112,050

The CCP area is suggested because of the availability of facilities, staff and equipment. Approx. 10 km of riverine habitat must be sprayed per treatment. Using 20m swaths = 20 ha per treatment. 3 insecticides at 4 rates of application = 12 treatments = 240 ha at 1 kg/ha = 240 kg required at $10/kg = $2400 + 50% allowance for possible spraying of both sides of the river = $3600.

Costs as at June 1975.

Appendix 5. Rotary wing aircraft applications of non-residual insecticides

Habitat	-	riverine gallery forests
Main species	-	G. palpalis, G. tachinoides
Location	-	West Africa
Insecticides	-	endosulfan and 1 alternative non-persistent insecticide
Application equipment	-	Bell 47G4 or 206 helicopter fitted with electrically powered rotary atomisers

Item	$
Entomologist 2 m/m	5,200
Application expert 1 m/m	2,500
1 field officer 2 m/m	1,500
12 fly boys 24 m/m	1,500
Supporting services 7 LR/m	5,950
Other costs	2,000
Insecticides	500
Helicopter (65 hours @ $1,200 per hour)	78,000
Total	97,150

Endosulfan to be used in preliminary trials to establish viability of technique. Approx. 5 km of river to be treated in each trial. This technique is only to be considered in emergency situations because repeated applications by helicopter are economically prohibitive.

Costs as at June 1975.

Appendix 6. Medium fixed wing aircraft applications of non-residual insecticides

Habitat	-	Savanna woodland
Main species	-	G. m. morsitans
Location	-	Botswana (Okavango area)
Insecticides	-	2 suitable non-persistent insecticides, endosulfan as reference
Application equipment	-	Medium twin-engined fixed wing aircraft fitted with rotary atomisers

Items	$
1 x entomologist 3½ m/m	7,750
1 x application expert 1½ m/m	5,650
Insecticides	7,000
Supplies and services 40 LR/m	3,400
Equipment (lab facilities etc)	3,000
Entomological assessments	
1 field officer	2,000
1 assistant field officer	1,300
12 fly boys	1,500
Land-Rovers 6 LR/m	5,100
Aircraft (50 hours flying @ $500 per hour)	25,000
Total	61,700

Each treatment block would be at least 4 km x 4 km = 16 km^2. Tsetse fly populations would be monitored pre- and post-treatment.

[illegible] 13 June 1977.

Appendix G

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Appendix II

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(by Subjects)

I. ECOLOGY AND ENVIRONMENT.

II. TRYPANOSOMIASIS--The Disease.

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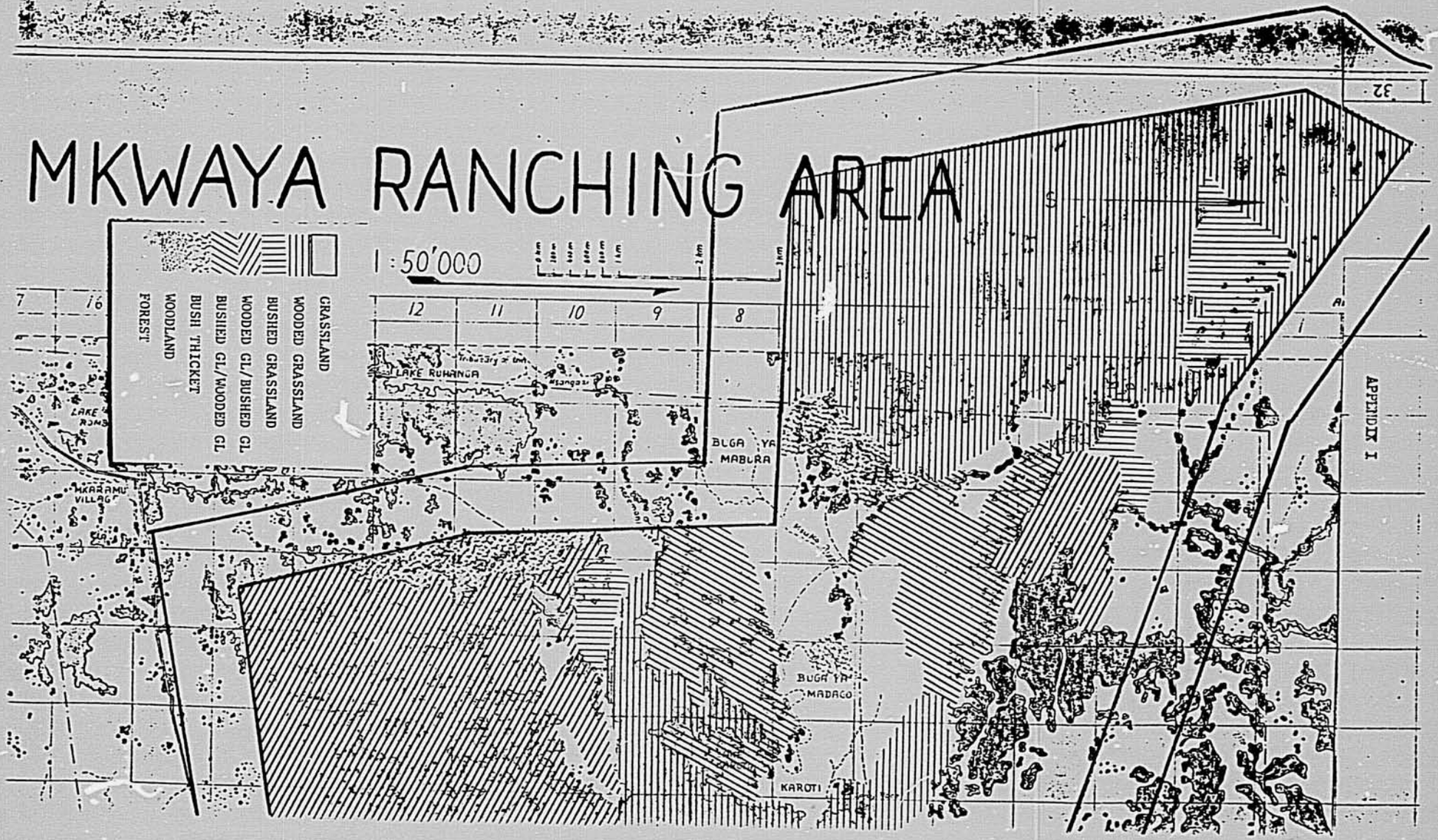
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