Area-Wide Control of Fruit Flies and Other Insect Pests

Edited by Keng-Hong Tan
Area-Wide Control of Fruit Flies and Other Insect Pests

JOINT PROCEEDINGS of the
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DEDICATION

This book is dedicated in memory of the life and work of the late Dr. Edward F. Knipling (1909-2000), who pioneered the area-wide approach to insect pest management. He also is known as the father of the sterile insect technique and promoter of other biological approaches to insect pest control. Dr. Knipling was not only a scientist, but also a philanthropist and a man committed to the search of solutions to problems faced by poor farmers in the developing world.
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FOREWORD

The organisation of these proceedings on the Area-wide Approach to the Control of Insect Pests is appropriate and timely. There is increasing interest in the holistic approach to dealing with major insect pest problems. This interest has been prompted by the steady progress scientists have made in the development of the sterile insect technique for eliminating the screw-worm from North America, the melon fly from Okinawa, the elimination and containment of the medfly in various countries and the progress that scientists have made in eradicating tsetse fly populations from isolated areas. Increased interest has also been shown by agriculturalists because of the realisation that the farm-to-farm reactive method of insect control is only a temporary solution to problems and that pests continue to be about as numerous as ever from year-to-year. In the meantime, there is increasing public concern over the environmental hazards created by the use of broad-spectrum insecticides to deal with insect pest problems.

While there has been progress in the area-wide approach to insect control it has not advanced to the extent that it should have. There are many other important insects that would be good candidates for area-wide management. Our agricultural leaderships in both the public and private sectors and many pest management scientists do not fully appreciate the large economic and environmental benefits that can be realised by directing control efforts against total pest populations in a fully organised manner. The sterile insect technique provides a feasible way to manage total insect pest populations. However, other techniques and strategies appropriately integrated into management programmes can increase the effectiveness and efficiency of area-wide management programmes. These include the augmentation of mass-produced biological organisms and the use of semiochemicals such as the insect sex pheromones.

These proceedings will give pest management scientists from many countries the opportunity to exchange information on the area-wide approach to insect pest management – an approach that if fully developed can be highly effective, low in cost and at the same time make a major contribution to alleviating the environmental concerns associated with primary reliance on broad-spectrum insecticides for controlling insect pests.

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December, 1998
PREFACE

With the world population attaining the six billion mark, the urgency of increasing quality food production and reducing the spread of diseases transmitted by insects, without affecting our fragile environment, will be of paramount importance. Losses currently experienced in agricultural production, due to insect pests and through diseases transmitted by insect vectors, are very high especially in developing and poor countries. Many insect pests and vectors are of economic importance, and several such as fruit flies, mosquitoes and tsetse flies have attracted international concerns. Most pests are traditionally controlled through heavy reliance on pesticides which can cause environmental pollution, pesticide resistance, and pest resurgence. The control, management or eradication of insect pests and vectors with minimal adverse impact on our food quality, environment, health and well-being should be of great concern to many agriculturists, biological and physical scientists as well as to national and international agencies responsible for pest control. Steps taken by the various concerned agencies to improve and implement the area-wide control will hopefully lead us into the next millennium free from major insect pests and vectors while at the same time protect our precarious global environment.

This volume is the culmination of proceedings conducted in two recent international meetings, FAO/IAEA International Conference on Area-Wide Control of Insect Pests, 28 May – 2 June 1998, and the Fifth International Symposium on Fruit Flies of Economic Importance, 1 - 5 June 1998, held in Penang, Malaysia. Over three hundred papers (both oral contributions and posters) were presented at the two meetings. The manuscripts submitted by authors are divided according to broad topics into eighteen sections originally defined by the organisers as corresponding to the sessions of the meetings. The organisers identified one to several individuals in each of the sessions to deliver an oral presentation of general and/or a specific interest, the subject matter of which is related to the respective sessions in the meetings.

This book is organised into parts that follow the sequence of the two meetings. Due to space and financial constraints, an international panel selected ninety-one papers for inclusion into this book. It contains an opening session and three parts, each with one to several sections consisting of invited contribution(s) and selected poster(s). Overview or review chapters form the major part of these joint proceedings. At the end of this volume are appended a) the final programmes of the two meetings reflecting further the diverse topics presented but not included in this book, and b) taxonomic, author and subject indices.

Moderation is the editing philosophy adopted. An attempt to improve readability and to standardise format and style was made without affecting the authors' inferences, interpretations and conclusions. The kind cooperation provided by the authors in checking edited proofs is greatly appreciated.

I am indebted to the Food and Agriculture Organisation of the United Nations, International Atomic Energy Agency, International Fruit Fly Steering Committee, Universiti Sains Malaysia, and Working Group on Malaysian Fruit Flies for their administrative and financial support; and to all the authors for their respective contributions to this book. The editorial assistance provided by Josephine Choo, S.T.
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Honourable Chief Minister of Penang,
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Distinguished Conference Participants,
Ladies and Gentleman,

On behalf of the Directors General of the International Atomic Energy Agency, in Vienna, and the Food and Agriculture Organisation of the United Nations, in Rome, and on my own behalf, I wish to extend a warm welcome to all participants of this International Conference on “Area-Wide Control of Insect Pests: Integrating the Sterile Insect and Related Nuclear and Other Techniques” at this beautiful location of Penang.

I would like to thank, most heartily, the Government of Malaysia for having accepted to host this conference and for facilitating its execution through the Universiti Sains Malaysia. I would like to place on record the appreciation by the International Atomic Energy Agency and the Food and Agriculture Organisation of the United Nations to the Government of Malaysia for being a reliable partner in promoting the peaceful use of nuclear technology in food and agriculture. I would also like to thank the Local Organising Committee for its cooperation and the excellent local arrangements made.

The International Atomic Energy Agency, IAEA, serves the United Nations family as the global forum for scientific and technical cooperation in the peaceful uses of atomic energy. Its aim is to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity. Within this context, it assists research on and the development of, practical application of atomic energy for peaceful uses.

The Food and Agriculture Organisation, FAO, is the leading agency in the United Nations for food and agriculture, and rural development. Its aim is to eliminate world hunger and rural poverty by assisting countries to increase agricultural production and by promoting the institutional and policy reforms required for sustainable development.

In 1964, the International Atomic Energy Agency, and the Food and Agriculture Organisation of the United Nations, in recognition of the commonality in their objectives and the complementarity of their roles, joined forces and established the
Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, and later the associated FAO/IAEA Agriculture and Biotechnology Laboratory. The mission of the Division is to strengthen capacity for using nuclear methods in various fields in food and agriculture, and to disseminate these through international cooperation in research, training and other outreach activities in Member States of IAEA and FAO.

In the field of insect pest control, the Joint Division has the mandate to help reduce insect-caused pre-and post-harvest losses as well as pesticide use and its negative impact on the environment. It does this through the development and implementation of environment-friendly nuclear and related technologies.

Following the important success achieved by Dr. E. F. Knipling and his group in the USA in the 1950s in the development and application of the Sterile Insect Technique against the New World Screw-worm fly, Member States requested the Joint Division to establish a programme to promote the development and application of the Sterile Insect Technique against key insect pests. As a result, since the early 1960s, the Joint Division has supported national, trans-boundary and sub-regional insect pest control programmes against major pests, and has played an important role in promoting the Sterile Insect Technique and related technologies.

The Sterile Insect Technique is the most environment-friendly method of pest management. It has proven highly effective against several key insect pests in controlling or even eradicating them across provincial, national, or regional boundaries. Unlike pesticides, which generally have a broad-spectrum lethal activity, the Sterile Insect Technique is species-specific, that is, it affects exclusively the reproduction of the target pest and not other useful insects. Sterile insects, mass-reared in large factories, are released by air on a sustained and regular basis into the target areas, substantially reducing fertile matings. As a consequence, the Sterile Insect Technique has no impact on the food or environment, does not affect beneficial species, and is compatible with most other types of control. Cost-benefit analyses have shown that the Sterile Insect Technique is economically competitive or even superior to conventional methods when considered over longer time frames. For developing countries, the use of the Sterile Insect Technique is also attractive because it reduces the need of expending hard currency for pesticide imports and creates labour opportunities in mass rearing factories. Finally, being area-wide in nature, the Sterile Insect Technique provides economic and environment benefits equally for large commercial farmers and small subsistence farmers, and the population at large.

For some key insect pests, considerable progress has been made over the last 35 years in the development and applicability of the Sterile Insect Technique. This includes large reductions in costs of mass rearing insects, as well as advances in technologies to process and distribute sterile insects and to monitor them in the field. For these pests, the use of the Sterile Insect Technique is no longer considered experimental - important successes for purposes of control, exclusion or even eradication have been achieved. Major successes include the eradication of the screw-worm from North Africa, North America and most of Central America, and of various fruit flies from Mexico, Chile, Japan, Australia and the USA. We are particularly proud that recently the Sterile Insect Technique was successfully used to eradicate the tsetse fly from the Zanzibar Island of Tanzania, indicating a very promising future for employing the technique in tsetse control or eradication programmes on the African continent.
In spite of these successes, most major insect pests still reduce global food output by about 25 to 35%. They transmit diseases that affect humans, livestock and crops, and continue to represent important barriers to free international trade in agricultural products. These high losses due to insects attacking crops, transmitting disease and inhibiting trade occur in spite of pesticide applications in agriculture continuing to increase world-wide. In 1995, world pesticide consumption reached 2.6 million metric tons of active ingredients, costing about US$32 billion annually. In developing countries, according to the most recent World Bank report on the environment, pesticide sales are on a strong upswing, and many highly toxic insecticides remain popular. In spite of Integrated Pest Management successes in reducing pesticide use in some crops such as rice, a significant overall increase in pesticide use is likely over the next decade at least, with pesticide sales growing at a rate of about 5% per year in India, China or Brazil. Pesticide use is particularly intense where such export crops as cotton, coffee, fruits, vegetables and flowers predominate, and for which the Integrated Pest Management approach has been less successful.

The present heavy reliance on chemical pesticides to control insect pests cannot be sustained in the future. Increasingly, there is pesticide resistance in target pests, as well as the emergence of new pests as a result of the elimination of their natural enemies by insecticides. Furthermore, public concerns have grown considerably as a result of widespread environmental pollution, contamination of groundwater, and the presence of pesticide residues in food and fibre. In view of this unsustainable reliance on chemical pesticides and public concerns, new and more environment-friendly techniques, approaches and strategies in the war against insect pests are called for.

Integrated Pest Management has been the dominant paradigm of pest control during the last 30 years with the objective of reducing pesticide use. However, traditional Integrated Pest Management is a localised strategy, with localised short-term objectives which are achieved by remedial interventions, generally based on insecticides to maintain local pest populations below economic injury levels. As pest insects from neighbouring populations keep moving into the treated areas, the effectiveness of these uncoordinated and reactive farm-by-farm, orchard-by orchard, or herd-by herd controls is therefore at best temporary, resulting in the frequent need to re-apply and eventual over-reliance and overuse of pesticides. Furthermore, for some crops such as vegetables and fruit, the economic damage thresholds are so low that the presence of even a few individuals of the pest often trigger the initiation of insecticide applications.

The concept of Area-wide Integrated Pest Management, which is the main focus of this International Conference, implies more than just extending local strategies to large areas. Area-wide management has longer-term objectives, and intervention strategies are planned and implemented on a regional scale. Area-wide Integrated Pest Management requires coordination between farmers and addresses the management of the total population of a pest in an area or region. This involves a strategy very different from traditional Integrated Pest Management in that the large-scale spatial distribution of the pest species has to be considered, both in cultivated as well as non-cultivated and urban areas. It also involves considering the temporal distribution of the pest to determine the periods when the pest is most susceptible to preventive, rather than remedial, interventions. When producers of a given area or region organise
themselves to take area-wide integrated action and target all individuals of the pest population, much less inputs are required and the control is usually more effective and sustainable. The area-wide Integrated Pest Management approach is central to the effective integration of the Sterile Insect Technique with other pest control technologies. At the same time, as will be described by several speakers in this Conference, it is also very effective when other pest management tools are integrated on an area-wide basis.

In summary, present trends show that we can look forward with confidence towards a more rational approach to manage major insect pests. Mounting public opposition against the risk of pesticide residues in food and the negative effects of the permanent insecticide treatments will continue favouring non-pesticide technologies. At the same time, the economic feasibility of using area-wide approaches will become increasingly apparent, firstly, with a more realistic accounting of the negative environmental effects of synthetic pesticide applications, and secondly, with further improvement in the cost-effectiveness of these methods as a result of continuing investment in applied Research and Development. Finally, world trade in agricultural commodities will continue to increase rapidly, together with the need for countries to overcome non-tariff trade barriers based on the International Plant Protection Convention. One can predict that these global trends, that are forcing growers towards further rationalising and integrating of activities into large production and trading associations, will strongly encourage an area-wide approach to pest control that integrates, for each pest and situation, the most appropriate pest management techniques.

However, as pointed out by Dr. Knipling in the Preface to the Book of Abstracts of this Conference, agricultural leadership in academia as well as public and private sectors, generally does not fully appreciate the large economic and environmental benefits that can be realised by directing control efforts against total pest populations in a systematic manner. A number of questions come to mind, which I hope will be debated and discussed by scientists at this Conference. Why is the area-wide approach not more widely applied in view of its obvious effectiveness, favourable economics and better sustainability? What are the major factors limiting its acceptance and implementation? Does the area-wide approach have to involve Government intervention? How can the area-wide approach be partially or totally commercialised? How can ownership and participation by academia in area-wide control be strengthened? What other major insect pests are viable targets for area-wide control? What other insect pest control approaches can be components of Area-wide Integrated Pest Management?

I am confident that the over two hundred scientists from over seventy countries and five international organisations represented at this Conference will critically review these and related issues and come up with recommendations that will move this field forward, and guide us over, the next 5-10 years in providing better support to our Member Countries in the field of insect pest control. The International Atomic Energy Agency and the Food and Agriculture Organisation of the United Nations look forward to receiving your recommendations.

Once again, I wish to thank the Government of Malaysia for accepting to host this important Conference, and the Universiti Sains Malaysia for the excellent local organisation.
I wish you successful deliberations and a pleasant stay in this beautiful country.

Thank you.
Welcome Remarks

P. J. Gomes
Chairperson, International Fruit Fly Steering Committee

Welcome everyone to Penang, Malaysia for the 5th International Symposium on Fruit Flies of Economic Importance. The fact that this is the 5th Symposium says a lot about how well we address the needs of the fruit fly community at large. The theme of this Symposium is: Fruit Flies: Current Global Scenario. As we come to the close of the second millennium and begin the next, it is indeed quite fitting to take a closer look at where we presently are with regard to the tools and approaches available to control these destructive pests and to consider where we want to be in the future.

When we talk about fruit flies, we must think and act globally to address the many concerns that these pests present both to agricultural producers and consumers. In order to meet the increasing demand for food security and safety, our agricultural systems must produce greater quantities of fresh fruits and vegetables in a more efficient and environmentally sound manner. Not only must we concern ourselves with the quality of goods produced, but we also must address new international standards for quality, nutrition, and freedom from pests and harmful residues. This Symposium aims to satisfy these needs.

Despite many improvements that have occurred since the last international fruit fly Symposium in Clearwater, Florida, fruit flies still predominate as major phytosanitary concerns among countries involved in the trade of fresh fruits and vegetables. Although world trade is expanding at a rapid rate, the mere presence of certain fruit fly species prevents the movement of fresh commodities from one country to another. Recent assessments on the economic and social impacts of certain fruit flies reveal that losses, direct and indirect, easily total in the millions of dollars each year. More importantly, potential benefits of their control can easily total 10-20 times those projected losses. This is why we now gather here in Penang, so that we, as an international community of fruit fly workers and researchers, can present and discuss new options and strategies for bringing about better exclusion, detection, and control of fruit fly pests.

Reflecting back four years to the last Symposium, I am pleased to report significant progress in many areas, both new and old, for dealing with these pests. This progress will be highlighted by the 33 speakers, 160 posters presentations and 14 discussion sessions involving 180 of our colleagues representing more than 40 countries and several international organisations. In addition, we consider ourselves very fortunate that the Food and Agricultural Organisation and the International Atomic Energy Agency approached us with their intention to convene its International Conference on Area-wide Control of Insect pests Integrating the Sterile insect and Related Nuclear and other techniques at the same venue. This provides for even greater opportunities for interaction and discussion with some of the world's best and most knowledgeable...
pest control specialists and scientists. This adds to the global dimension of both events, and their participation is most welcome. A joint proceedings of the Conference and Symposium will be published very soon.

On behalf of the International Steering Committee and all the Symposium participants, I would like to thank the Universiti Sains Malaysia, the Working Group on Malaysian Fruit Flies, and members of the Secretariat and Local Organising Committee for all their hard work arranging this Symposium. I especially wish to thank Professor Tan Keng Hong and his devoted staff for their many hours of preparation for a successful Symposium. I wish you all a productive and enjoyable stay here in beautiful Penang.
PART I.

AREA-WIDE APPROACH: CONCEPTS AND ECONOMICS
Pest Management Strategies: Area-wide and Conventional

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INTRODUCTION

Man has fought a war with insects for centuries. With few exceptions, man has been on the defensive.

Neither side has won the war, but both have won battles. Man has managed to contain the damage caused by insects that transmit diseases and limit food and fibre production well enough that the human population has increased significantly over the centuries. The insect control successes have been primarily a result of utilising toxic chemicals against pest insects. Alternatives to insecticides to reduce the damage caused by insects are now receiving more attention because of the perceived environmental problems with the continuous use of insecticides in a defensive battle against insects.

One of the curious and discouraging things about insect control is the lack of high technology methods available for the producer or homeowner. The insect has no such problem.

Insects use an outstanding array of high technology methods of fighting the war. These include genetics to develop resistance to insecticides and other methods of control, genetic selection of the strongest individuals, genetic adaptability that prevents natural or man-made disasters from eliminating the species. The insect sensory mechanisms are outstanding. A few molecules are all that are needed to locate mates or food.

Producers and homeowners continue to use the same low technology method that has been used for many years: a sprayer and an insecticide, the universal tools to control insects.

Conventional Insect Control

The usual approach to insect control is to treat the commodity only after a damaging population of insects has developed. In other words, the producer, home owner or casual gardener fights a defensive battle. He reacts to an insect attack. When he sees the enemy or the damage caused by the enemy, he loads up his sprayer with an insecticide and mounts a counter attack.

Most insect control procedures are applied by an individual producer on his own relatively small production area. This conventional insect control approach encourages the producer to make his own decisions about whether or not any insect control is to be used, which insect control method or product to use, when to use it, how to use it, who applies it, etc.

Advice to producers on insect control is usually available from government extension personnel, private insect control consultants or representatives of companies that sell insecticides or other insect control materials or methods.
The conventional procedure results in great variability in the efficacy of insect control because each producer makes his own decisions.

**The objective of conventional insect control is to protect the commodity. This is usually accomplished by treating the commodity, be it cows or corn or rice in a warehouse.**

Conventional insect control requires virtually no planning to achieve results. The "programme" is short-term, frequently measured in days until the next insecticide application is needed. It is reactive (defensive).

**Area-wide Insect Control**

Area-wide insect control is applied against an important insect pest over a relatively large area involving many individual producers of the same or similar crops. The "area" is a combination of geography and the range of hosts of the target insect pest. The term "area" in "area-wide" refers to the area where the target insect population survives. The area is not limited to production of the major crop(s) to be protected.

It is very likely that a large part of the cost of an area-wide programme will be fighting the target pest away from the commercial production – before the commercial crops are susceptible – on wild or alternate hosts or abandoned orchards, untreated host plants in homeowners’ gardens, etc.

In most cases, area-wide insect control will be the responsibility of a separate organisation hired by the producers.

A separate organisation can plan an aggressive offense against the target pest population over the entire area. High technology systems can be effectively utilised to plan the population management programme. Included will be satellite imagery to detect alternate hosts, sensitive methods to detect movement of the pest populations, computer programmes to predict changes in the pest insect population based on biological parameters, a systems approach to utilise natural enemies on an area-wide basis, genetic analysis to detect the development of resistance and utilisation of systems to delay the development of resistance over the total area.

Further, area-wide programmes encourage the use of specialised methods of insect control that are not effective or are not used on a farm by farm basis. These include the sterile insect technique (SIT), male annihilation, inundative releases of parasites, mating inhibitors, large-scale trap cropping with very attractive plants, treatment of alternate hosts on public lands and hosts in private gardens, etc.

**The objective of area-wide control is to reduce the pest population within the target area to a non-economic level. This is accomplished by attacking the entire pest population in the target area.**

Conventional insect control attempts to protect the plant or animal, is carried out by individual producers over a small area with little planning, is short-term, low technology and is a reactive (defense) approach to insect control.

Area-wide insect control attempts to reduce the pest population to a non-economic level over a large area involving many individual producers, is conducted by a special organisation which will carry out a thoroughly planned long-term proactive (offense) approach to insect control. High technology systems that reduce costs and environmental problems and increase efficacy will be used.
SOME EXAMPLES

Insects

There are more examples of area-wide insect control than most plant and animal protection specialists believe. Included are:

- all SIT programmes,
- all insect eradication programmes,
- most forest insect control programmes,
- in certain cases, host plant resistance are applied on an area-wide basis,
- mosquito control programmes,
- the Black Fly programme in West Africa, and
- fumigation of silos or buildings.

Most of us are familiar with cockroaches. Many of us live in apartment houses. Cockroach control in apartment buildings offer a simple example of area-wide control. Treating an individual apartment will control the cockroaches in that apartment for a few days or perhaps a few weeks. But the pests will return rapidly, moving into the treated apartment from adjacent untreated apartments. Thus the individual apartment owner has great difficulty controlling cockroaches unless his neighbours also treat against cockroaches.

If the people in the apartment building agree that every apartment will be treated during one week, the roach population is greatly reduced, except in the garage, utility rooms and the garbage room. These are common areas and not owned or occupied by any one individual. The apartment dwellers may say, “Why should I pay for treating the garbage room. I do not live there and I do not care if there are cockroaches there”. (This is the same attitude that many producers have when they are asked to pay for insect control on land that is not theirs.)

Thus to achieve long lasting roach control in an apartment building, the entire structure must be effectively treated.

The target of this approach is the total roach population in the building and not the cockroaches in any one apartment.

When correctly done, cockroaches will have been essentially eradicated from the building. They will of course re-invade the building from neighboring structures or by being carried into the building with food stuff. However, long-term control has been achieved and the cost of roach control for the individual apartment dweller has been significantly reduced.

Non-insects

Other agricultural pests are also susceptible to the area-wide concept. Examples are weeds, plant diseases, nematodes, rats, birds, etc.

The management of human diseases is becoming more area-wide oriented. The eradication of smallpox is the best example. The mass inoculation of school children against various diseases is a type of area-wide disease management. The treatment is to the individual child but the objective is more than to protect that single child. It is to prevent the spread of the disease from child to child with a possibility of a large epidemic.
Most of our grandfathers and great grandfathers used individual wells for a water supply; they had no sewer system, transportation was the horse owned by the individual, they did not have a communication system such as a telephone, etc. The development of these individual services into "area-wide" services resulted from the recognition that some services can be done better and cheaper by using an "area-wide" approach. The profit motive was also important.

I believe the same to be true for key insect pests.

TARGET INSECTS

The selection of the target pest is important. In the case of eradication programmes, SIT programmes, programmes to control mosquitoes, black flies, tsetse flies, screw-worms, etc., the selection has already been made.

Selection of target insects species for new area-wide programmes is more difficult. It is likely that the programme will be built around a single species.

The pest must be of major importance in a large area.

One place to start would be the selection procedure used for host plant resistance. Another would be the target species for insecticide companies. Of particular importance would be to select "key" insects. "Key" insects are those that cause extensive damage and that if controlled, the producer directly benefits financially. Some examples are Heliothis, boll weevil, tsetse fly, screw-worm, some fruit fly species, diamond back moth, etc. Some of these are already the targets of area-wide programmes. Many other candidates for area-wide control programmes can be identified.

TECHNOLOGY

Specific technology for use in area-wide control or management programmes is limited. The reason for this is not the difficulty of methodology but that educational institutions do not emphasise the concept of area-wide control sufficiently. Insect pest management (IPM), a defensive procedure that is practised on a field by field basis, receives most of the attention of our universities at the expenses of insect population management which is the basis of area-wide control.

The lack of incentive for research scientists to conduct research leading to area-wide control is a major deterrent to area-wide control programmes. This research is more expensive than working on a few insects in the laboratory or evaluating an experimental insecticide in small plot field tests.

The available special technologies depend to a large extent on advanced technology, such as satellite imagery, weather forecasting, very early detection of resistance, very sensitive trapping/detection methods, genetic manipulations to improve parasites and insects used in SIT programmes, the use of radar to detect long range movement of insects, etc. This is the opposite of what the individual producer uses for conventional insect control -- the sprayer and an insecticide.

The practitioner of area-wide control will integrate conventional and special technologies into a programme that attacks the pest insect population within the target area. Included are:
• SIT,
• male annihilation,
• parasites and predators,
• trap crops,
• host plant resistance,
• mating inhibitors,
• insecticides, chemical and biological, and
• physical control methods.

The difficulty is to put the pieces together so that control is effective, cheap and environmentally acceptable over the entire area.

ORGANISATION

In most cases, the producers will not operate area-wide insect control programmes. They do not have the time, the knowledge nor the interest. Further, the expenditure of monies to control the pest on non-commercial plants (wild hosts) on non-productive lands (wild hosts), in urban gardens (alternate hosts that city people will not treat), on abandoned fields (non-treated hosts) is hard for producers to accept. Yet in many cases these are the key to a successful area-wide programme.

When establishing an area-wide programme, it is essential to understand that there are a large number of stakeholders (affected and interested people). These people will have a great influence on success or failure of the project. These include:

• producers,
• wholesalers,
• exporters,
• plant and animal protection scientists,
• university plant and animal protection personnel,
• extension workers,
• environmentalists,
• economists,
• labour unions,
• bankers, and
• politicians.

Planning the area-wide programme is essential. It must be done thoroughly and in detail. The following aspects must be covered in detail:

• producer support,
• legal,
• operational organisation, and
• technology to be used.

Other important aspects include research (done by others) that can improve the programme, public relations to keep information available and a sound economic analysis that supports the programme.
Producer Support

The producers (all of them) should be members of a producer organisation or a special organisation established for the area-wide programme. If some producers are opposed to the programme, difficulties can be expected unless there are means to "encourage" them to join the programme.

The producers will be the primary source of funds to operate the programme. Detailed agreement must be reached with the producer organisation for several years’ funding.

Producer support is mandatory for successful area-wide programmes.

Legal

A well planned legal agreement between the operational organisation and the producers’ organisation must be negotiated. It must identify the degree of insect control, penalties for poor results, responsibilities of both the producers and the operational programme, insurance coverage, including personal liability insurance, etc. Possible environmental problems must be covered. The legal document must also very specifically identify funding sources, accounting procedures and possibly insurance against fraud.

The legal agreement must be negotiated professionally and not between friends.

Operational Organisation

A professional organisation must be established to operate the programme. Personnel must be trained to their assignments. All must understand clearly their duties and responsibilities, accountability, rewards for excellent performance and penalties for poor performance. All must have well prepared job descriptions.

Professionalism at all levels and in all contacts is essential.

Technology

Technical plans for the area-wide campaign must be prepared in detail. The technology will change over time as the operational staff become more familiar with the problem and new technology is developed by research scientists. Automation should be used wherever possible as it reduces human error, increases efficiency, and reduces the relatively high and ever increasing cost of labour.

CONCLUSIONS

Area-wide insect control:

- will provide improved efficacy, cost saving and environment,
- is a long-term approach,
- offers excellent opportunity to use high technology methods,
- is an offensive strategy not a defensive one,
- usually requires a separate operational organisation, and
will initially target a single species but eventually will expand to crop protection.

The requirements for success in area-wide insect control programmes include:

- use only proven tested control methods,
- research is not conducted within the programme,
- prevent political control of the programme, and
- establish an independent organisation to operate the programme.

An area-wide insect control programme is a long-term planned campaign against a pest insect population in a relatively large predefined area with the objective of reducing the insect population to a non-economic status.
Area-Wide Approaches to Insect Pest Management: History and Lessons

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INTRODUCTION

World agriculture is now entering a very trying era because currently our numbers (Figure 1) are expanding by more than 90 million additional people per year. Demographers project that our growth will not drop below 90 million people per year until about 2020 (United Nations 1993, Nygaard 1998).

The challenge is to increase food production every three or four years sufficiently to feed an additional population equivalent to that of Western Europe or North America.

![Figure 1](image1.png)

Figure 1. The number of additional people added to the world population each year.

The land available for agriculture on a per capita basis (Figure 2) is becoming progressively more limited so than in 2010, on average, 1 hectare in developing countries will have to feed 5 people, and in South Asia, 1 hectare will have to feed 8 people (Alexandratos 1995, Klassen 1995).
Figure 2. Number of people whose food will have to be produced on one hectare of land in 2010.

On an average, 66 percent of the additional food must come from increased yields (Figure 3), and in South Asia, fully 80 percent must come from increased yields. The balance will come from expanding the area cultivated and use of intensified cropping systems. However, this is not a simple matter since pest populations tend to be favoured by yield-boosting measures.

Since population growth rates recede as people overcome poverty, and since increasing food production is the principal means of overcoming poverty in many countries, it is imperative that in the decades immediately ahead major improvements be made in reducing losses to pests and in other yield enhancing measures (UN Department of International Economic and Social Affairs 1993, Alexandratos 1995, Klassen 1995).

Figure 3. Sources of yield increases in 93 developing countries and in South Asia.

NEAR INVINCIBILITY OF INSECTS

Insects continue to be the major competitor of man. Although we have been able to increase food production greatly, we have not made headway in reducing overall losses caused by insects. Our insect competitors have proved much more resourceful
than we could imagine, and we are forced to rethink our approaches of dealing with them.

The great antiquity of insects gives them a tremendous advantage (Metcalf 1991). Insects first appear in the fossil record of the Lower Devonian Period about 390 million years before the present (Myr BP). The Class Insecta has diversified into 27 orders, about 945 families and several million species. During these 400 million years, insects have surmounted very diverse challenges, and the winning gene combinations have been retained in their germlines. Within their gene pools, insects have the genetic information to meet almost any imaginable challenge.

Insects have a tremendous numerical advantage. For every human on earth, there are 200 million insects (Metcalf 1991). The desert locust, Schistocerca gregaria Forskal may form swarms of as many $13 \times 10^8$ individuals per swarm – twice more individuals than the number of people on the whole earth (Uvarov 1977). Metcalf (1991) stated, “Such swarms eat their own weight of vegetation daily, an estimated $1 \times 10^4$ metric tons, and can cause almost total destruction of agriculture wherever they alight.” An outbreak of the desert locust is very dangerous since it may spread in 60 countries over 20 percent of the earth’s land surface and threaten 10 percent of the world’s human population with starvation (FAO 1998).

ORIGIN OF AREA-WIDE APPROACHES

Probably, migratory locusts were one of the plagues that caused prehistoric man to attempt forms of group or area-wide control. Since migratory locust swarms can be seen approaching from a distance and descending onto crops, it seems likely that people banded together and used whatever means at hand to stamp out as many as possible. No doubt invasions of armyworms, leafcutter ants and other insects caused people to cooperate in combating them (Howard 1930).

In China since 707 B.C., more than 800 outbreaks of Locusta migratoria manilensis L. have been recorded along the floodplains (Figure 4) of the Hwang, Huai and Chang Jiang rivers. In 1929, an outbreak devastated 4.5 million hectares of cropland. Consequently, about 120 million people were mobilised to modify the floodplains by damming, terracing and reforestation. Over almost 30 centuries, the Chinese slowly developed an area-wide pest management programme that now folds together knowledge of biology, ecology, forecasting cultural practices and water management (Metcalf and Kelman 1980, Metcalf 1991).

During the late 1920s, catastrophic locust plagues were widespread in Africa and Southwest Asia. Boris Uvarov and Zena Waloff of the British Ministry of Overseas Development, responded by establishing the International Unit of Locust Research. This unit became the Antilocust Research Centre and it provided the focal point for international cooperation in coping with plagues of the desert locust, the red locust and the African migratory locust. The Centre created databases and a sustained regular flow of information on the status of locust populations throughout their ranges. The Centre developed a system of monthly forecasting. Uvarov was able to interest FAO in creating the International Desert Locust Information Service to coordinate forecasting and the planning of campaigns. Leadership in these vitally important functions has been assigned to FAO’s Locust Group (Waloff and Popov 1990).
Doubtless, the scientific pioneers of area-wide approaches were influenced strongly by concepts from the field of public health and hygiene. About 2,500 years ago, the Greek spirit and the Roman capacity for organisation had produced a highly developed system of hygiene in what is now southern Europe. The Romans procured safe supplies of water by means of aqueducts, practised daily bathing and removed garbage from cities. Why did they do this? Varro (116 BC-27 BC), who served Pompey and Julius Caesar, asserted that malaria is caused by minute living creatures. He wrote, “In damp places there grow tiny creatures, too small for us to see, which make their way into our bodies...and give rise to grave illness” (Sigerist 1958). However, with the collapse of the Roman Empire and the storms of folk migrations, classical hygiene eroded. Nevertheless, raging outbreaks of malaria, typhoid, typhus and bubonic plague during the later Middle Ages re-awakened concepts of hygiene and public health. Doctors and public authorities joined forces to erect walls against these plagues. Dr. Johann Peter Frank (1745-1821) had considerable success in persuading the rulers of Europe during the late 1700s and early 1800s to establish public hygiene policies and to enforce them vigorously. While only a 21-year old student at the University of Strasbourg, Frank called for “systematic action by the authorities” to intervene in the lives of all citizens in order to forestall or halt epidemics (Sigerist 1958). The discoveries of Pasteur, Koch and others on the nature of diseases were foundation stones for rational policies of public health.

Thus through collective action within communities, even without an overall national plan and central coordination, malaria in southern Europe and North America largely disappeared in consequence of education, the universal adoption of window screens, destruction of habitats of Anopheles larvae and the treatment of all cases with quinine (Collins and Paskettwitz 1995).

Investigations conducted in the late 1800s and in early years of this century on the transmission by mosquitoes of deadly diseases led to the widespread use of area-wide programmes. Yellow fever, dengue, filariasis and malaria were shown to be transmitted by various species of mosquito. In 1892, Howard and in 1900, Ross began to recommend that the habitat of mosquito larvae over extensive areas be either treated
with kerosene or drained. These practices were first implemented in West Africa to combat malaria (Stage 1952), and soon adopted by communities in many countries. By 1912, the New Jersey Mosquito Extermination Association was founded, and it provided the model for the organisation and operation of area-wide mosquito abatement districts of which there are about 260 in the United States and a thousand or more world-wide.

**POWER OF SOCIAL CONCERNS**

Some of the programmes conducted on an area-wide basis – especially those aimed at eradication – have aroused opposition. The strategy of eradication emerged just over one century ago as the brainchild of Charles Henry Fernald of the University of Massachusetts. Under Fernald's leadership, Massachusetts attempted to eradicate an introduced pest, the gypsy moth, *Lymantria dispar* L., in an 11-year campaign from 1890 to 1901. Initially, the primary eradicant was Paris green spray (Forbush and Fernald 1896). The use of Paris green, which suffered from modest efficacy and phytotoxicity, had to be abandoned because of adverse public reaction.

Forbush and Fernald (1896) noted, “Considerable opposition to the use of Paris green for spraying was manifested by many people living in the infested towns. A mass meeting of opponents of the spraying was held in Medford. One citizen, who attempted to cut the hose attached to one of the spraying tanks, and threatened with violence the employees of the Board who had entered upon his land, was arrested and fined. Others neutralised the effects of the spraying by turning the garden hose upon trees and shrubs that had been sprayed, and washing off the solution. The opposition to the spraying affected the results of the work unfavourably to a considerable extent.” Clearly, apathy by many members of the public had turned into outrage.

Thus the social dimension of pest management was revealed in a new way with emphasis on stakeholders who are not primarily concerned with the economic dimension of the pest problem. Repeatedly, applied entomologists have learned the hard way that the ecological, environmental, social and human health criteria are more important to some stakeholders than the economic criterion (Rabb 1972, Dreistadt 1983, Scribner 1983, Myers, Savoie and van Randen 1998).

One hundred years passed before social scientists such as Sandman (1987) and Starr (1985) taught us to analyse programmes for outrage factors, and to be proactive in dealing with issues in order to avert outrage. Indeed, our inadequate expertise in coping with social and political aspects has resulted in many setbacks and difficulties (Perkins 1982).

In 1955, the World Health Assembly urged WHO to lead and organise worldwide eradication of malaria (Wright, Fritz and Hanworth 1972). By 1959, almost 65 percent of the people at risk were protected and this percentage rose to 74 percent by 1970. Malaria eradication was claimed in 37 countries, and the incidence of malaria had dropped dramatically in many countries. In Sri Lanka, the number of cases dropped from more than 2.8 million per year to just 17 in 1963 (Metcalf 1991), but then the effort floundered as WHO was unable to deal with the widespread hue and cry for local control. In 1969, the Global Programme disintegrated. Soon, DDT was banned in the United States and WHO's resources for malaria were re-allocated. Malaria resurfaced to more than half a million cases per year in Sri Lanka and to more than 100 million cases world-wide (Collins and Pasetkwitz 1995).
In 1969 and 1970, the Indian Council for Medical Research and the WHO initiated several projects relevant to area-wide control. Unfortunately in 1974, these projects became the target of a press campaign by writers who feared that these projects were actually a USA-funded effort to develop methods of biological warfare. Since the government of India was unable to restore confidence, the projects were terminated (World Health Organisation 1976).

LEGAL AUTHORITY

Area-wide control owes much to the love of wine by Europeans. In about 1860, the grape phylloxera, *Phylloxera vitifoliae* Fitch was transported from the United States to France. Within 25 years of its arrival, this insect had utterly destroyed 1 million hectares of vineyards or fully one-third of the productive capacity of France. In order to protect the German wine industry, the government of Germany in 1873 passed the first law that provides for quarantines and regulatory control of agricultural pests (National Academy of Sciences 1969). Other governments quickly followed the example set by Germany. Without such legislation, it would be impossible to prevent the entry or establishment of exotic pests or to limit or retard their rate of spread. Meanwhile, the French sought the assistance of the charismatic American entomologist, Charles Valentine Riley. In 1871, Riley set the French on an area-wide programme of grafting all European grapes on the phylloxera-resistant American rootstocks (Summers 1925).

The discovery in 1889 by Theobald Smith and colleagues that cattle fever is caused by a tick-transmitted parasite of red blood cells led to the initiation in 1906 of a county-by-county effort to eliminate the two *Boophilus* tick vectors from the United States (Figure 5). Many pastures were rendered tick-free by excluding all host animals until all ticks had starved to death. Livestock were dipped in an arsenical solution at two-week intervals. Quarantines were used to prevent the movement of infested cattle into areas that had been cleared. By 1943 – after 37 years of gruelling effort – the ticks had been eliminated entirely from the United States at a total cost of about US$40 million or the equivalent of the annual losses suffered before the programme was initiated (Cole and MacKellar 1956, MacKellar 1942). Quarantines have been effective in preventing these ticks from becoming re-established from their populations in Mexico. A broadly shared vision sustained this programme in spite of war and the great economic depression.

CONTRIBUTIONS OF NATURAL ENEMIES

I believe that area-wide pest management was practised more widely during the nineteenth than during the twentieth century. During the eighteenth and nineteenth centuries, people began to understand the roles of natural enemies in preventing insect outbreaks. Further, the powerful synthetic insecticides were not available to allow smallholders independently to protect their crops and livestock. The beneficial work of coccinellids and other predators had been common knowledge for centuries, and they were collected and distributed for insect control (DeBach 1964). However, insect parasitism was discovered only around 1700 by Leuwenhoeck in the Netherlands and in 1706 by Vallisnieri in Italy. Significantly, Emperor Francis I of Austria ordered Vincent Kollar to publish his work on the role of natural enemies in suppressing pests.

Figure 5. Progress in eradicating *Boophilus* ticks in the United States 1906-1943.

That classical biological control can provide area-wide solutions was dramatically illustrated against an exotic pest in California in 1888 and 1889. At that time an introduced pest, the cottony cushion scale, *Icerya purchasi* Maskell, was killing hundreds of thousands of citrus trees. However, Albert Koebel was able to introduce a scale predator, the vedalia beetle, *Rodolia cardinalis* Mulsant from Australia and New Zealand. Less than 11,000 vedalias were distributed, but they spread throughout the entire citrus growing area of southern California and saved the industry (see DeBach 1964, Klassen 1991). The vedalia beetle continues to effectively protect citrus in California, and nothing needs to be done other than to avoid the use of certain insecticides, which would decimate this invaluable natural enemy.

Almost exactly one hundred years after the great vedalia success, a team led by Dr. Hans Herren of the International Institute for Tropical Agriculture (IITA) successfully implemented the largest classical biological control programme in history (Figure 6). In 1973, cassava near Brazzaville and Kinshasa was found to be attacked by the cassava mealybug, *Phenacoccus manihoti* Matile-Ferrero. In a few short years, immature crawlers were dispersed by wind throughout sub-Saharan Africa.

The cassava mealybug created starvation and hardship for many of the 200 million people for whom cassava had become a staple crop. In 1981 an excellent parasitoid, *Epidinocarsis lopezi* DeSantis – found in Paraguay by A. C. Bellotti – proved capable of bringing the cassava mealybug under control. The parasite was mass reared and released by aircraft over 38 countries of sub-Saharan Africa (an area much larger than the combined area of the United States, Mexico and India) with excellent results (Herren and Neuenschwander 1991). This singular accomplishment required strong and imaginative leadership and action by IITA, generous funding by donors, and brilliant scientific and technical work by Herren’s team and their cooperators in Africa, Europe and the Americas.

Uses of natural enemies and habitat modification have proved to be the only durable insect management techniques (Klassen 1991).

In many cases, natural enemies are effective only if most smallholders in an area work to conserve them. Since both pests and natural enemies are mobile, their populations distribute themselves throughout the region in which their food sources are
available. Even smallholders who do not participate in the conservation programme receive some of its benefits. They get a free ride. This is a positive externality. On the other hand, the movement of natural enemies off the property of the participating farmer to that of the free rider is a negative externality (Reichelderfer et al. 1984). The brown planthopper, *Nilaparvata lugens* Stal, has been the scourge of rice production in Southeast Asia for many years. However, during the 1980s, Indonesia, with technical assistance from FAO and GTZ, simultaneously achieved substantial increases in rice production and major reductions in insecticide use. Generally, brown planthoppers are effectively controlled by indigenous spiders and other predators (Heinrichs 1991, Oka 1991). Moreover, since insecticides have a greater impact on the predators than on the pest, the brown planthopper populations are able to resurge after being sprayed. In the past, farmers induced resurgence by beginning to spray 40 days after transplanting the rice. However, cage studies showed that the smallholder who delays spraying until 65 days after transplanting saves two insecticide applications and realises a yield increase for a total benefit of US$588 per hectare.

![Figure 6. Biological control of the cassava mealybug in sub-Saharan Africa through the introduction of a parasite from Paraguay.](image)

THEORETICAL BASIS OF AREA-WIDE APPROACHES

Reichelderfer et al. (1984) modelled what happens when some smallholders delay spraying to conserve natural enemies but others do not (Figure 7). If about ten percent of smallholders conserve natural enemies, they gain only one-fifth of the potential benefit. If 30 percent of smallholders conserve natural enemies, they gain only one-quarter of the potential benefit and the free riders gain about 7 percent. When 50
percent of smallholders conserve natural enemies, they gain one-third of the potential benefit and the free riders gain about 18 percent.

![Graph showing benefits of increasing participation in biocontrol programme.](image)

Figure 7. Benefits of increasing participation in biocontrol programme.

When 70 percent of smallholders participate, they gain almost 60 percent and the free riders gain about 40 percent, and when 90 percent participate they gain about 83 percent of the potential benefit, while the free riders gain 66 percent. Clearly a conservation programme is almost futile until about one-half of the smallholders participate, and the programme becomes progressively more beneficial as the percent participation increases toward 100.

An attempt to explain the theoretical basis of area-wide pest management was made by Knipling (1992). Knipling noted that apple growers achieve almost 100 percent control of codling moths *Cydia pomonella* L., in major apple growing areas, but that in these communities, there is often an abandoned orchard or some untreated non-commercial trees. Because of these tiny reservoirs – normally less than 5 percent of the total host resources of the pest – the codling moth is able to build to economic numbers throughout the entire apple growing region. Thus, Knipling used a simple population model to compare the overall trends of a total population in an ecosystem subjected to uniform suppression versus one in which a small part of the population escapes treatment each generation. The model showed that, in five generations, a field in which 10 percent of the population escaped treatment would produce 1000 times more insects than in a field in which the total population is suppressed uniformly in each generation. Thus, Knipling formulated the principle, "Uniform suppressive pressure applied against the total population of the pest over a period of generations will achieve greater suppression than a higher level of suppression on most, but not all, of the population each generation."

**COPING WITH PEST MOBILITY AND EXTERNALITIES**

In some instances, high pest mobility and externalities can be met only by employing the sterile insect technique, pheromones or by the release of natural enemies on an area-wide basis. During the past five decades, theoretical models and practical experience have shown that, whenever possible, highly selective control measures should be chosen. If the pest must be strongly suppressed or eradicated, then a method that is effective against high density populations and a method that is effective against
low density populations should be integrated in such a way that the former potentiates the latter, especially if the goal is eradication (Knipling 1966, 1979, Klassen 1989).

Control measures, whose effectiveness is greatest against low-density populations, include sterile insects and sex attractants. Without such techniques, it would have been impossible to eradicate the screw-worm or tropical fruit flies from southern Japan (Yamagishi et al. 1993), Australia (Fisher 1994) and Mexico (Orozco et al. 1994). Systems including the area-wide use of sex pheromones are now emerging to manage the pink bollworm, Oriental fruit moth, tomato pinworm and other lepidopterous pests (Carde and Minks 1995). Knipling (1992) promulgated his view that many parasitoids have phenomenal abilities to find their hosts and that such parasitoids are highly efficient even when the host density is low. This hypothesis needs to be evaluated in an area-wide context. For total population management of pests with fairly high economic thresholds, the integrated use of two or more methods effective against high-density populations tends to be effective and durable.

CONTINGENCIES OFTEN DICTATE STRATEGY

Terms of reference and contingencies have a tremendous influence on the selection of strategies of area-wide pest management. Peter Geier (1970) wrote a brilliant paper entitled “Temporary Suppression, Population Management or Eradication: How and When to Choose”. He stated that the title “implies that we face a true choice, and that proper attention to the facts of the matter should lead us to the “right” decision. But what is “proper attention”, what are “relevant facts” in this context, and, finally, by what criteria can we judge a practical decision to be “right”, or to be “wrong”?”. Geier notes, “I have become convinced that the honest answer ... is simply this: as specialists, as experts, as economic entomologists, we hardly ever choose the course of our actions deliberately. That course is determined for us, not by the guidelines of our trade, but by the terms of reference, largely subjective and contingent, that govern our operations. Those are the real decision-makers. As such, they might deserve more notice than they usually receive in our specialist circles.”

Geier’s stricture applies to the epic struggle to remove the New World screw-worm, Cochliomyia hominivorax Coquerel, from North America. To accomplish this goal, different area-wide strategies had to be selected to meet different situations. As known, eradication is the destruction of every individual of a species in an area surrounded by natural or man-made barriers sufficiently effective to prevent re-invasion except through the intervention of man (Newsom 1978).

The process began in 1954 on Curacao (Figure 8) where the strategy of eradication was executed successfully, and then again in Florida. In Florida, one-quarter of the cost of the programme was borne by the cattle industry, one-quarter by the state and one-half by the federal government. Subsequently, a cost-shared programme was implemented in the states bordering on Mexico. The parasite was eliminated from Texas and New Mexico, Arizona and California. However, the parasite population in the adjacent area of Northern Mexico was managed to minimise the number that would enter the United States. Eradication could not be the immediate strategy because eradication was contingent on having an agreement between the governments of Mexico and USA to remove the parasite from Northern Mexico. It took six years to reach an agreement, and only then could the eradication strategy be resumed.
Meanwhile during 1966, no screw-worms could be found in the United States for several months. Thus, the cattle industry and the state governments were able to persuade the US Secretary of Agriculture to declare that the parasite had been eradicated from the United States. This declaration caused the screw-worm to be considered a foreign pest, and thus the federal government became solely responsible for any costs that would be incurred when screw-worms reappeared in the United States. Therefore the border states and the cattle industry were able to avoid cost-sharing the programme after 1966. However, numerous screw-worm cases (Figure 9) occurred in USA until 1982.

In 1977, the late Dr. L.D. Newsom of Louisiana State University voiced a concern felt in many universities. Newsom noted that the screw-worm had not been eradicated in fact but by fiat – namely by an authoritative pronouncement of the USDA. Newsom noted that this lack of candour "has caused grave problems for our profession by generating far too much optimism for its general applicability as the ultimate in strategy of pest management." Newsom stated, "Keeping in mind that the objective of the screw-worm programme is to eradicate the pest from the United States, we can only conclude that there has been abysmal failure to achieve that objective. Reaction to such failures to achieve eradication has become characteristic and highly predictable. The typical procedure is to increase the size of the operation without bothering to do the necessary research required to explain the failure encountered at the previous level of operation. This does not seem to be a reasonable approach. Nevertheless, this is precisely what has happened with the screw-worm programme."
Around this time, a movement to discredit the strategy of eradication arose in the United States, and this movement hampered work against the boll weevil, *Anthonomus grandis* Boheman. Tremendous controversy developed within the scientific community during the early 1970s when the United States Department of Agriculture (USDA) mounted a large-scale experiment to assess the feasibility of eradicating the boll weevil from the United States. The losses caused by the boll weevil were far greater in the eastern and southern parts of the pest’s range than in the northern and western zones. Thus, in the event that the boll weevil was removed from the Cotton Belt, cotton acreage would shift from the west to the east – to the detriment of Texas and to the benefit of the eastern states.

This large pilot field experiment was conducted in 1971-1973 in southern Mississippi, Alabama, and Louisiana (Figure 10) to assess the feasibility of eradication. The test area included the primary eradication area (*Zone 1*) surrounded by three buffer zones. The eradication area had a radius of about 40 kilometres and the entire experimental area had a radius of about 120 kilometres. Very intensive suppression was implemented in the two inner zones. However, the two outer zones received only...
normal in-season control by growers and insecticide applications applied on a diapause control schedule. The boll weevil was suppressed below detectable levels in 203 of 236 fields in the eradication zone. All of the 33 lightly infested fields were located in the northern one-third of the eradication zone and less than 40 kilometres from substantial populations farther north in the buffer. In the southern two-thirds of the eradication zone, no reproduction could be detected in any of the 170 fields (Committee on Appropriations 1975).

![Figure 10. Pilot boll weevil eradication experiment in Louisiana, Mississippi and Alabama.](image)

The USDA leaders concluded that the experiment indicated that the technology was sufficiently effective to achieve eradication. Their experience with the screw-worm had convinced them that the achievement of total elimination of all individuals from the target area following the first application of the suppressive system is not necessary.

Eradication is accomplished iteratively. The first application of the suppressive system clears the pest from most of the target zone. Subsequently, surviving populations are delimited and suppressive measures are applied to them. In this iterative fashion, the aggregate range occupied by the pest is progressively reduced toward zero (Klassen 1989).

However, neither the experiment’s Technical Guidance Committee (Knipling 1976), a committee of the Entomological Society of America nor a committee appointed by the National Academy of Sciences, recommended initiation of an eradication programme (Entomological Society of America Review Committee 1973, National Research Council 1981, Perkins 1983). Nevertheless, the cotton industry insisted that a trial eradication programme be undertaken. The programme started in Virginia and North Carolina (Carlson and Wetzstein 1993). By phases, this programme has removed the boll weevil from about 4.5 million acres in seven states. The weevil has been removed from one-third of the Cotton Belt. Cotton acreage has shifted strongly to the states that no longer have the boll weevil.
SOME AREA-WIDE PROGRAMMES MAY DAMAGE ENVIRONMENT

The boll weevil programme relies heavily on applications of malathion to all cotton in an eradication zone. Under dry windy conditions, these applications tend to decimate the natural enemies of the beet armyworm. Thus in the Rio Grande Valley in 1995, a catastrophic outbreak of the beet armyworm was induced. Consequently, the growers terminated the eradication programme. Ecologically selective technology exists, but it costs more than the use of malathion. Unfortunately, the US Congress reduced the share of federal funds to less than 15 percent, and thus short-term costs are decisive in designing the boll weevil pest management system.

FORESTALLING INSECTICIDE RESISTANCE

Genes for susceptibility to insecticides are beginning to come under area-wide management by the US Environmental Protection Agency (EPA) (Carlson et al. 1998). EPA controls the registration of pesticides and the release of transgenic crop cultivars. The gene for the Bacillus thuringiensis toxin has been incorporated into corn, cotton and other crops. Since these lepidoptera-resistant resistant corn and cotton cultivars are planted on millions of acres, there is concern that resistance to Bt will develop rapidly. To avert this, EPA has mandated a resistance management programme whereby in 1996, 3.85 percent of each cotton field had to be planted with non-Bt cotton and left untreated with insecticides. Alternatively, if the grower wished to use insecticides other than Bt, then 20 percent of the field had to be planted with non-Bt cotton. EPA also placed limits on total sales of Bt-corn in cotton producing counties in order to prevent the corn earworm from developing resistance to Bacillus thuringiensis (Carlson et al. 1998).

CONTRIBUTION OF HOST RESISTANCE

The benefits of area-wide use of pest-resistant crop cultivars can scarcely be overstated. Even a difference of 50 percent between resistant and susceptible varieties, which is cumulative each generation, greatly reduces the pest's density (National Academy of Sciences 1969). Fields planted with resistant cultivars serve as traps for pests. Moreover, resistant crop cultivars greatly facilitate the effectiveness of natural enemies, cultural methods and insecticides but when used alone, insects commonly overcome host resistance in three to ten years (Klassen 1991).

SUPPORT OF ENVIRONMENTALISTS NEEDED

Rachel Carson's book, Silent Spring, which appeared in 1962, gave very strong support to the development of ecologically selective tools for pest management (Carson 1962). However, we have failed to effectively enlist the support of the environmental community for area-wide programmes. Worse, the United States Environmental Protection Agency has a history of opposing area-wide programmes which are highly beneficial to the environment. There is a need everywhere to engage
the environmental movement and to lead it to an understanding of the great benefits to
the environment that can be derived from well-conceived area-wide programmes.

URGENT NEED TO ADVANCE AREA-WIDE APPROACHES

History has produced a harmonious body of theory, principles and practices to
guide and support successful area-wide pest management programmes. This conference
is only a tiny part of what needs to be done to transmit this body of knowledge to the
next generation of students and workers. It is very urgent that we extensively replace
field-by-field management with area-wide strategies. Otherwise, we will not fulfil our
obligation to future generations. In order to provide for future generations, we must
make major progress in the next two decades. Let us not underestimate our splendid
competitors who have had 400 million years to assemble genes for the battle. We can
imagine their confident rallying cry: “vincero, vincero, vincero!”.

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Economics of Area-Wide Pest Control

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INTRODUCTION

Area-wide pest management is commonly practised throughout the world, probably much more so than is generally recognised (Lindquist 2000, Klassen 2000). Apart from highly publicised area-wide schemes such as the sterile insect technique (SIT) for fruit flies, pheromone disruption for cotton bollworms and classical biological control, there are many examples of actions such as concerted host plant eradication, enforced closed crop seasons, organised pesticide rotation for resistance management, coordination of resistant crop genotypes, etc., some going back several centuries, which should also be considered as area-wide practices. Each of these is faced with many of the economic issues generally associated with area-wide management which will be discussed below.

In general, there are to be four major questions to answer in devising an area-wide pest management programme:

• Should a particular pest be controlled locally or area-wide?
• What is an appropriate area over which management should be attempted?
• Within that area what form of control is most efficient?
• What level of organisation should be used to get the job done?

It should be noted that apart from clearly objective measures such as technical effectiveness (say, mortality) or cost efficiency (mortality per dollar), there are many subjective measures that come into the evaluation of area-wide control due to the element of risk (for example, in quarantine and eradication), the boundaries of externalities (for example, variable probabilities of pesticide drift under different conditions or target organism sensitivities) and time preferences for returns on capital investments (such as insect rearing facilities or research to develop pheromone technologies). As a result of these subjective components, it may sometimes be difficult to reach clearly agreed decisions based on objective economic analyses, even with a consensus on the data used.

PRINCIPLES

There are three general classes of economic problems in comparing pest management options:

• annual comparisons (for example, pheromone disruption),
• initial capital costs with delayed projected benefits (SIT eradication),
• and
• initial costs with delayed and uncertain future benefits (quarantine, pesticide resistance management).

In any of these cases, the two basic principles governing the selection of area-wide management over individual local pest management are effectiveness and efficiency.

Quarantine and eradication can only be achieved on an area-wide basis; they are unlikely to be effective otherwise. In both cases, total effectiveness is required and this must be the paramount indicator. Questions of efficiency subsequently arise in deciding which area-wide techniques to employ, not in comparing them to uncoordinated local control. However, economic efficiency should be considered at an early stage to decide whether total control, as epitomised by quarantine or eradication, is a viable option.

In suppression campaigns it is quite possible to choose a less effective control if it is much less expensive or more practical to use. Suppression may or may not be more effective by area-wide management, but the main issue is one of cost efficiency. Is area-wide suppression more cost efficient than the sum of local management? This is in fact quite a challenge because, in many areas of local pest management, private returns of 4:1 are commonly obtained, or at least perceived (Pimentel and Lehman 1993).

A basic conflict can arise between technical analyses of pest management and economic analyses because of their respective emphases on effectiveness and efficiency. Technical leaders of programmes naturally strive for the ultimate effect, such as eradication, while economists may point out that a less ambitious goal with lower technology and costs may give a greater return and pose less risk of financial loss. To this, the technologist can argue that technological development requires risk taking and a greater good could be found by extending the boundaries of space and time to include a wider potential. Unlike the technologist – who can look towards an objective perfect indicator of success – economists, like lawyers, must refer to a subjective norm, in effect the risk attitude and willingness to pay of a “reasonable” person, often as represented by their political agents in government. The latter, because they are merely agents, are often even more averse to risk than the sum of society itself (Stonehouse and Mumford 1994). Politicians in fact do not merely reflect public attitudes; they may amplify them. We must accept that there may be irreconcilable differences in the attitudes of the people running programmes and those paying for them.

PROBLEMS

The fundamental problem of economic analysis for area-wide pest management must be in deciding (and then convincing others) that the results expected and the measures used are indeed “reasonable”. Let us consider some of the component problems.

Scale

For some projects, the scale of operations is predetermined by geographical or political boundaries, such as the eradication of Bactrocera dorsalis (Hendel) in Mauritius or Ceratitis capitata (Wied.) in Florida. Either the entire area infested or the
entire area within one political jurisdiction must be included, and the costs and benefits are determined for that entire area. But where management is being considered for only part of an infested area (for example, fruit flies in South Africa, or tsetse flies in East Africa) the extent and characteristics of the area chosen can have very substantial effects on the benefit:cost calculations, due to the relative values of production, costs of controls, area of non-crop hosts, presence of related pest species, etc., in different parts of the total infested region.

For the eradication of fruit flies in South Africa, Mumford, Tween and Barnes (1997, 1998, unpublished) calculated the returns on a SIT eradication for each of 19 fruit growing districts in the Western Cape province in early 1998. In the most favourable district eradication (to be achieved in one year and lasting three years) is predicted to have a five year net present value gaining approximately US$1.5 million, while the least favourable district would have a value losing approximately US$2.0 million. By including some areas and excluding others, an optimal economic return can be obtained; fruit fly control throughout the Western Cape would not be economic over a five-year period, even under the most optimistic assumptions made in the technical plans (under current export market standards, more stringent residue restrictions in the EU would make eradication or SIT suppression more attractive). However, if only high return areas are managed, political questions arise: if public money is used, should uncontrolled areas be compensated, or should the management be privately funded by those who will benefit?

This question becomes even more complex in border areas, such as in the Middle East, where fruit flies in citrus may be controlled in Jordan, Israel and Palestine, within a few kilometres of each other (Enkerlin and Mumford 1997). The prices and market conditions for citrus are different and the level of control currently used also differ considerably because of economic circumstances in the orchards in each territory. The benefits in Israel, where fruit flies are effectively, if not efficiently, controlled by insecticides from area-wide fruit fly SIT are largely in reduced pesticide inputs with lower residues and less environmental damage and continued access to discerning high value markets. In Jordan and Palestine, however, the main advantages would be in reduced crop damage. Due to political boundaries, it may in many cases, be necessary to manage different aspects of the programme at different scales, for instance regional/international surveillance, but national or district level control, etc.

The economic advantages of being able to concentrate on high return areas are clear and this may pose additional technical challenges to area-wide management to produce sharp and effective boundaries that would allow, in effect, pest management gerrymandering.

**Time and Discount**

A frequent claim for eradication programmes is that they are "forever" and that, therefore, future benefits should be calculated in perpetuity. As a result, even small annual benefits would justify large initial eradication costs. However, it is unreasonable to include infinite streams of benefits, not least because we know from experience that quarantine can fail and the process may need to be repeated. Furthermore, we must discount future benefits to balance them against present (or near future) expenditure. This is done using a discount rate that measures the value of having money now compared to some time in the future. The most common calculation of the discount rate is to subtract the national inflation rate from the bank interest rate for savings, which will generally produce a figure around 4% or 5% in developed countries. This
represents the "reasonable" person's discount on the future; they put their money in the bank because they are paid this premium, otherwise they would spend it now. So, the benefit of eradication next year is worth 5% less if it is brought back to the present. Benefits in 20 years are only worth 37% of their face value when brought back to the present. In riskier economic environments discounts rates will be much greater. At 15% discount, a benefit 20 years in the future is only worth 6% of face value at present.

Two other options for calculating discount rates should also be mentioned. It could be argued that there are greater returns available than saving money in a bank, and if it was possible to gain 25% per year from some other form of investment such as stock markets or currency speculation, then the opportunity cost of foregoing this investment should also be added to the discount. At a discount rate of around 25% a benefit 20 years in the future is worth only 1% of its face value in the present. At the other extreme, it is sometimes argued that social benefit should be calculated using a social discount rate. An individual values money today more than in the future because he may die, or otherwise lose the opportunity to spend it, before the future arrives. Society, on the other hand, is relatively timeless and could place equal values on future and present good, effectively producing a discount rate of 0%.

So the total present value derived from an economic analysis must reflect a reasonable time period and discount rate. Conservative analysis would use shorter time periods and higher discount rates and may present a range of options to indicate sensitivity. Time is more arbitrary than the discount rate, since the latter can be reasonably objectively calculated. Time horizons in the range of 10-20 years are commonly used (Kehlenbeck 1996, Cox and Forrester 1992, Mumford et al. 1995, 1996), unless a project is expected to wind up sooner (Table 1).

Time horizons are mainly of concern in cases in which projects have substantial initial capital expenditure preceding a long benefit stream. Mumford et al. (1996) indicated annual input savings from pheromone control of pink bollworm in Egypt in the range of US$5 to US$9 million for 1995 (depending on the inclusion of environmental costs), but also projected that this annual benefit was likely to decline steadily over 15 years due to decentralised cotton management and a reduced cotton area (Table 2). It cannot, and should not, be assumed that input savings pertain to a static production or protection system.

Table 1. Summary of benefit indices for SIT eradication of codling moth in the Suweida and Damascus regions of Syria, without including environmental benefits (Mumford and Knight 1996).

<table>
<thead>
<tr>
<th>Economic Benefit-Cost Indicators</th>
<th>10 years</th>
<th>12 years</th>
<th>15 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pay-back period in years to break-even (discounted net)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Total cost US$,000 (no discount)</td>
<td>11011</td>
<td>11739</td>
<td>12913</td>
</tr>
<tr>
<td>Total direct benefit US$,000 (no discount)</td>
<td>13300</td>
<td>16940</td>
<td>22400</td>
</tr>
<tr>
<td>Net present value US$,000</td>
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<td>351</td>
<td>1484</td>
</tr>
<tr>
<td>Net benefit/cost (no discount)</td>
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<td>0.443</td>
<td>0.735</td>
</tr>
<tr>
<td>Internal rate of return (no discount)</td>
<td>0.069</td>
<td>0.114</td>
<td>0.146</td>
</tr>
<tr>
<td>N/K (return on equity, discounted)</td>
<td>0.845</td>
<td>1.087</td>
<td>1.369</td>
</tr>
<tr>
<td>Discount rate</td>
<td>0.10</td>
<td>Interest on capital</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Table 2. Projection of input and environmental savings (£'000) from reducing 2.5 sprays per year for pink bollworm on Egyptian cotton (Mumford et al. 1996); pheromone use - phased in from 1992.

<table>
<thead>
<tr>
<th>Year</th>
<th>Value of 2.5 sprays saved</th>
<th>Environmental value of 2.5 sprays saved</th>
<th>Annual benefits from adoption of pheromones from 1992</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(phased in from 1992-5 and out from 2000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>431</td>
<td>2,831</td>
<td>2,831</td>
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<tr>
<td>1993</td>
<td>2,680</td>
<td>7,482</td>
<td>7,482</td>
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<tr>
<td>1994</td>
<td>9,496</td>
<td>18,823</td>
<td>18,823</td>
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<tr>
<td>1995</td>
<td>32,050</td>
<td>42,293</td>
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<tr>
<td>1996</td>
<td>28,325</td>
<td>37,644</td>
<td>37,644</td>
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<td>1997</td>
<td>28,325</td>
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<td>2000</td>
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<td>2001</td>
<td>22,660</td>
<td>30,115</td>
<td>30,115</td>
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<td>2002</td>
<td>19,827</td>
<td>26,351</td>
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<tr>
<td>2003</td>
<td>16,995</td>
<td>22,586</td>
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<tr>
<td>2004</td>
<td>14,162</td>
<td>18,822</td>
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<td>2005</td>
<td>11,330</td>
<td>15,057</td>
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<tr>
<td>2006</td>
<td>8,497</td>
<td>11,293</td>
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<tr>
<td>2007</td>
<td>5,665</td>
<td>7,529</td>
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<tr>
<td>2008</td>
<td>2,832</td>
<td>3,764</td>
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</tr>
<tr>
<td>2009</td>
<td>0</td>
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<td>0</td>
</tr>
</tbody>
</table>

Valuation

Two forms of net benefit calculation can be considered, input comparisons and economic surpluses, as used by Cox and Forrester (1992) to analyse the benefits of insecticide resistance management. Input comparisons are attractive because they are easily valued, since pesticides and other inputs have known prices. Such an analysis is particularly appropriate for annual comparisons of net benefits in cases where both forms of control give very high levels of control, for instance cotton bollworm control (Knipling and Stadelbacher 1983, Mumford et al. 1996). An environmental estimate may be added to the input comparison (Mumford et al. 1996).

Economic surpluses are intended to show the overall impact on the economy due to a practice. This takes into account not only the changes in pest management inputs, but also the possible stimulus to investment in other inputs such as fertiliser, seed and land that improved pest management might encourage. Very great improvements in pest management may even affect crop prices by changing production. Many of these changes are very difficult to predict, although there are examples of studies that give indications of farmer responses to improved pest management in some areas (Napit et al. 1988, Kazmierczak 1996).

Not all benefits from pest management can be calculated directly from practically observable data. Reduced pest damage and savings in present control costs are the most immediate benefits that can be estimated. Other benefits must be converted into monetary units, often by subjective means. Two examples are presented, environmental and health benefits, and aesthetic benefits.
Environmental and health benefits arising from improved (area-wide) pest management can be estimated based on reduced pesticide load. Pimentel et al. (1993) estimated that the environmental cost of pesticide use was approximately US$19.00/kg/year in the USA, over and above purchase price. This included impact on humans and other organisms based on a combination of likely exposure, value of life, cost of treatment and loss of work in the case of humans and an arbitrary value for individual animals poisoned. Mumford et al. (1996) adapted the technique to determine environmental savings from area-wide cotton pest management in Egypt using the ratio of per capita income in Egypt and USA (less than 3%) to adjust this figure for Egypt, which resulted in an estimate of an environmental cost of US$0.52/kg/year. This was felt to be a considerable underestimate, given factors such as the greater risk of exposure to insecticide in Egypt (through direct and indirect contact), the greater proximity of households to agricultural areas and the importance of the agricultural sector in Egypt. Subjective weightings were put on these factors and a modified value of US$5.00/kg/year was assumed (just over 25% of the US value). While still subjective, this figure gives at least some measure of the importance of environmental savings from reduced pesticide use on Egyptian cotton.

In addition to input and environmental savings, aesthetic benefits may need to be estimated in some area-wide pest management. Miller and Lindsay (1993) estimated the benefits of area-wide gypsy moth control in New Hampshire, USA, where the principal benefits are better visual impact of undefoliated trees for residents and possibly greater tourism revenue from visitors. The benefits were estimated using the contingent valuation method to determine the public’s willingness to pay for control. Mean values were US$13-US$28 million/year (~US$38/ha/yr) and median values were US$8-US$17 million/year (~US$25/ha/yr) (the range depending on the interpretation of non-respondent views in the surveys).

The adoption of area-wide pest management eventually becomes a political process. Kazmierczak (1996) describes the process for adopting boll weevil eradication in southeastern USA, where decisions are generally based on public referenda. These generally require at least 67% of growers in an area to agree, then all growers are required to participate, and pay the assessed charges. Because of the use of referenda and at least partial payment and management by growers, these eradication efforts have a high level of grower “ownership”. Votes are influenced by the likely charge for the area-wide programme. He quotes potential reductions in “yes” votes of 5% for each US$2.50/ha assessed, so the estimation and perception of value from area-wide control can be critical to their establishment. In the case of the gypsy moth valuation noted above, the mean value may give a good estimation of the actual worth of area-wide management, while the median gives a better picture of the perceived worth to the typical voter, the “reasonable” person economists and politicians aim at.

A particularly important factor affecting adoption in Kazmierczak’s review was knowledge of the success of previous area-wide pest management programmes.

Risk

Quarantine is an aspect of pest management that involves analyses of probability and risk even more than most others (Bartlett 1996). Two models of economic analyses for quarantine can be considered. Kehlenbeck (1996) has suggested that quarantine is viewed as merely delaying the introduction, spread and damage of a pest and that the value of quarantine can be estimated by comparing the present value of the stream of losses expected with and without quarantine, up to the point, where in
both cases, the damage has reached its full potential. This is a rather pessimistic view of quarantine and does not really consider risk at all, since it relies on a discreet change in the expected rate of spread, rather than a probability change.

An alternative view of quarantine is that its effect is to impose a continual shift in the probability of introduction, establishment and damage, which may be more or less depending on how rigorously it is conducted, and how vigorously it is challenged by pest invasion or transport. The pest challenge and quarantine effort probabilities may be independent (but not necessarily so, since some of the pest challenge is related to human transport, which may be deterred by quarantine). These are clearly quite difficult to assess in practice, given a lack of actuarial data, but in theory, the annual value of quarantine could be estimated by:

\[
\text{Annual quarantine value} = \text{annual expected cost (with Q)} - \text{annual expected cost (no Q)}
\]

in which each of the annual expected costs is the probability weighted sum of the combined costs of quarantine operations (if any) and losses from pests that evade quarantine. A very simple example of this could involve a "no Q" case in which there are two states, loss of US$0 (p=0.75) and loss of US$10 million (p=0.25). A "with Q" case could have two different annual states (due to quarantine costs and efforts) with costs of US$1 million (p=0.9) and loss+cost of US$8 million (p=0.1). In this case, both the quarantine effort and the pest challenge have changed, and the overall annual value comes to:

\[
\text{Annual net value} = [-1 * 0.9 + (-8 * 0.1)] - [0 * 0.75 + (-10 * 0.25)] = \text{US$0.8 million}
\]

In reality, continuous probability distributions would be estimated, either directly from data on recorded introductions and damage and/or by panels of expert opinion.

**Capturing Returns**

It is increasingly important in public pest management that some of the benefits are used to repay the costs of the action, as has always been the case with private pest control. Authorities inevitably wish to recoup some of the costs through charges on participants but some forms of area-wide control are more amenable to this than others. Closed seasons and insecticide resistance management are examples of strategies that are difficult to charge for directly on a per use basis, although much of the cost is borne by farmers forgoing options to plant out of season or use particular pesticides. In some cases, charging for some forms of area-wide control, such as quarantine inspection or phytosanitary certificates, is potentially a disincentive to participation and could undermine the effectiveness of the programmes.

Pheromones and SIT, however, have good potential for capturing returns through commercial sales or privatised management. This is already common in the case of pheromones, and is likely to be increasingly common for SIT where it is used for suppression, rather than eradication. In general, in eradication programmes, the period in which sterile insects are used is too short to offer a reasonable opportunity to
recover the cost of private investment in a rearing facility. However, in suppression programmes, a reasonable profit over a much longer period can repay private investment in facilities and avoid the need for publicly initiated or coordinated control programmes to add to public debt (Enkerlin and Mumford 1997). The relatively easy and efficient transport of some sterile insects by air may allow commercial competition on price and quality and opportunities for specialisation and economies of scale in production facilities.

CONCLUSIONS

There is little doubt that many forms of area-wide pest control offer effective and efficient pest management, even to the extent of pest eradication. The larger scale of operations in many cases offers opportunities for a wider range of techniques, generally with less harmful environmental impact, to be used. The professional coordination required to manage pests on an area-wide basis involves technicians who can ensure that practices retain their specified design and standard. At least in theory, area-wide control offers the opportunity to integrate economic and environmental externalities within the programme so that decisions more appropriately reflect the true costs and benefits.

The main area in which problems lie with area-wide pest control appears to be in the mechanisms for public participation. Reports over many years cite technical, economic and environmental success with the concept but there is still indifference, reluctance and antagonism. There are several reasons for this related to attitudes and perceptions (Norton and Mumford 1993). There is a natural tendency in many people to want to manage their own affairs, either out of sheer independence or a belief that they can do it better than their neighbours, despite a lack of empirical evidence. Ignorance or disbelief in the effectiveness or efficiency of area-wide programmes is a factor which can to some extent be overcome by good publicity. And finally, these attitudes may be the result of a lack of opportunity for involvement and ownership of programmes, which may be seen as being imposed from above/outside, managed by technocrats or otherwise not arising from or meeting the needs of the people directly concerned. None of these issues should be insurmountable, but it is worth noting that area-wide pest management is an activity in which social participation and attention to the "reasonable person" is as important as technical proficiency.

REFERENCES


Trade Issues and Area-Wide Pest Management

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Food security and economic security are unarguably desirable objectives for all nations – indeed for the world. Equally important is the sustainability of designs that achieve these objectives without disadvantaging others or damaging the environment. Considering area-wide pest management in the context of these interrelated global policy forces is essential to fully understand its role in both the protection of plant resources and in facilitation of trade.

The case for food security begins with the realisation that there are currently about 800 million people in the world who are suffering from malnutrition due to lack of food. The World Food Summit, convened in November 1996, urgently called for coordinated world-wide action to ensure “food for all”. A key strategy for realising this goal is reducing losses due to plant pests.

In this light, area-wide pest management can be viewed as a valuable addition to the toolbox of pest management strategies. It can also be one of the most sustainable and cost-effective options to consider for pest management. However, just as the problem of world hunger is not solved by a single farmer, area-wide pest management cannot be successful at the individual level. It requires commitment and cooperation to make it feasible – the same type of commitment and cooperation that was expressed at the World Food Summit.

Where economic security is concerned, one need not look far to see a world of growing economic integration and widening circles of development. As the World Trade Organisation celebrates the 50th anniversary of the rules-based trading system which began with the General Agreement on Tariffs and Trade (GATT) after World War II, it is clear that globalisation and the liberalisation of trade have become permanent fixtures in international policy formulation and are integral to the economic security of all nations. Now, more than ever before, the world’s prosperity rests on maintaining an open international economy based on commonly agreed rules.

The significance of agriculture in this international economy is quickly evident, as we see enormous quantities of fresh and processed agricultural commodities racing across borders and seas to markets in the far corners of the globe where the availability of such products had been inconceivable only decades before. For every country in the world, the import and export of agricultural products are essential to the health of the economy as well as the population. Non-industrialised countries, in particular, rely upon agriculture as a cornerstone for commerce. Industrial countries rely upon trade in agricultural products to provide the quantity, quality and variety of goods demanded by modern consumers.

However, more trade, faster trade, and the opening of new markets for agricultural products also offer greater opportunities for the movement of pests that can have deleterious consequences. This raises significant concerns in policy formulation, especially as measures for protection can affect the free movement of commodities in trade. On the one hand, countries need to be able to import, to meet their needs and...
market demands, and they have the reciprocal need to have their exports accepted by others. On the other hand, countries must exercise a certain amount of care to ensure that they do not unduly jeopardise their own resources by introducing harmful new pests. This must be considered against the corresponding need to ensure that they do not ship harmful pests to other countries.

As a result, there emerges a strong need for a balanced, dynamic, multidisciplinary approach to policies concerned with pest management – for both domestic and foreign pest management. These policies are increasingly based on international cooperation, sophisticated technologies, and the marriage of economic and biological analyses. We are currently experiencing this transition in practice based on a more holistic approach, as evidenced in part by the expanding interest in applications for area-wide pest management. The evidence indicates that this shift will bring significant benefits in increased production and trade, as well as offering more sustainable and environmentally acceptable pest management options.

There is also the concern that as tariffs and other barriers are removed, countries may impose measures under the guise of protection in order to secure market or other unfair advantages. It is the nature of quarantine to follow the old adage, "an ounce of prevention is better than a pound of cure", i.e., it is comparatively cheaper and easier to prevent the entry of pests with strongly restrictive measures than it is to deal with the result of pest introduction. But while a certain degree of care is clearly justified, unreasonably conservative policies are seen to unnecessarily restrict trade. The question revolves around the issue of justification.

As globalisation and the liberalisation of trade have matured, and international trade in agricultural products has grown in importance, it has become necessary for "free trade" and "fair trade" to evolve still further to embrace the concept of "safe trade". That is to say, disciplines are necessary to ensure that protective measures are used to the extent justified by legitimate concerns, but not as unjustified barriers to trade.

This brings the discussion to the early part of the 1990s and the last round of multilateral trade negotiations under the GATT – the Uruguay Round, and the agreements therein related to agriculture. Emerging from these negotiations was the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) which dealt specifically with the issue of measures to protect plant, animal and human health and life. The SPS Agreement provides discipline to the use of protective measures in order to prevent such measures from being used as unjustified trade barriers.

The SPS Agreement is structured around several key principles, beginning with the sovereign right of a country to put protective measures in place, but balancing this with the obligation to ensure that such measures are justified. The SPS Agreement further describes such justification as being based on scientific principles and evidence, which are considered in the framework of a systematic evaluation process known as risk assessment. A number of other very important principles and definitions are found in the SPS Agreement which are not critical to the discussions here except to say that the sum of these represents a blueprint for establishing proper measures as well as for evaluating the measures of others.

A key point to note is that the SPS Agreement gives countries the option to base their measures on risk assessment or on international standards. It then goes further by identifying the sources for such standards in the three disciplines: plant health (phytosanitary), and animal and human health (sanitary). The Codex Alimentarius is responsible for food safety, the Office International des Epizooties (OIE) addresses animal health, and the International Plant Protection Convention (IPPC) is the
organisation named in the SPS Agreement as the source of international standards for phytosanitary measures, including measures for pest management where these affect trade.

Prior to the SPS Agreement, the IPPC had led a relatively quiet existence as an international treaty deposited with the Director-General of FAO. Since 1951 when it was adopted, the Convention's most distinguishing feature had been the Phytosanitary Certificate, a harmonised format to be used by countries to certify the phytosanitary status of shipments for export. It is on this certificate that pest management measures are noted, especially as they pertain to requirements which may be specified by the importing country.

The SPS Agreement suddenly placed new expectations on the IPPC, resulting in a series of consultations involving members, regional plant protection organisations and FAO with the objective of making necessary adjustments in the Convention and its activities. Included in these initiatives was the formation of a Secretariat, the launching of an ambitious programme of standard setting, and the negotiation of the New Revised Text of the IPPC to better reflect contemporary practices and the new role of the Convention in standard setting.

As the IPPC advanced into standard setting, members quickly defined priority subjects for standards. This soon led to the adoption of several important documents, including: Principles of plant quarantine as related to international trade; Guidelines for pest risk analysis; Glossary of Phytosanitary Terms; and the Code of Conduct for the Import and Release of Biological Control Agents.

Each of the above listed documents contains important elements of pest management, providing valuable guidance for the development of appropriate harmonised systems and also for evaluating the systems of others. More recent standards, such as Guidelines for surveillance (recently approved) and Requirements for the establishments of pest free places of production (near completion), provide additional information and another level of detail related specifically to pest management or components of pest management strategies.

As additional standards are added, and still greater detail is agreed upon, the standards will become increasingly more valuable. However, this framework of standards already offers significant utility to national plant protection organisations, particularly where pest management systems have an important role in trade. By using standards to the extent possible for designing and implementing pest management systems, countries reduce the level of analytical resources needed to design systems which can be expected to withstand the scrutiny of trading partners and also meet the obligations of governments under the IPPC and the SPS Agreement. The standards serve not only as models for developing measures, but also as reference points for evaluating or challenging the measures of others. They offer both conceptual and technical guidance.

Some highlights from the Convention and current standards that are relevant to area-wide pest management include:

- obligations for cooperation, information sharing, surveillance, pest listing, pest risk analysis,
- definitions for critical terms such as pest, area, and establishment,
- setting out the principles of area freedom and areas of low pest prevalence – recognising that pest presence is associated with areas rather than political boundaries, and that pest absence or low prevalence may be used as the basis for phytosanitary certification,
• describing the essential components of pest free areas – systems to establish freedom, measures to maintain freedom, and checks to verify that freedom has been maintained,

• establishing the principle of equivalence – accepting measures that are not identical but have the same result,

• elaboration of the principle of managed risk – accepting that zero-pest risk is not feasible and that the strength of measures used to manage risk should be based on the level of risk and the appropriate level of protection,

• defining and describing risk analysis – basing measures on a systematic assessment of the risk using scientific principles and evidence, and both biological and economic data,

• identifying key elements of surveillance – distinguishing between general and specific pest surveillance and outlining components of each, and

• identifying situations that enhance success – natural barriers, the isolation of growing areas, and targeting commodities that are marginal or poor hosts.

Although there is as yet no specific standard for area-wide pest management, the fundamentals for the development of such guidelines are in place. In the meantime, the existing principles and standards present no obstacles to the acceptance of area-wide pest management as a viable phytosanitary measure, and in fact reinforce its acceptance and application. By continuing to elaborate additional guidance in standards, the complexity of the concept can be reduced. Through the increased recognition and reliance on standards in policy making, its acceptance in practice can be further expanded.

There are also other factors which are not directly linked to international phytosanitary standards, but which argue for further development and more applications of area-wide pest management. A particular concern is the growing number of problems associated with traditional pesticide treatments. Field and postharvest treatments with pesticides are rapidly falling from favour, and those that can be used, often adversely affect product quality. Through the skilful management of pests at an area level, pesticides can be eliminated or dramatically reduced, thereby mitigating the inherent problems associated with safety, health, pest resistance and environmental damage. In situations where treatments are unavailable or unsatisfactory, this can be a very strong motivation for area-wide pest management.

In addition, it should be noted that the use of area-wide pest management as a phytosanitary measure toward the objective of “safe trade” is only a limited application of the concept. There are additional opportunities to address non-commercial concerns as well. For example, there are very useful applications for protecting human health, but this does not mean that phytosanitary standards cannot also be used to provide guidance. There are elements of good surveillance practice which are largely generic, and the feasibility of an area-wide pest management programme will always involve roughly similar analytical inputs such as cost/benefit analyses to support decision making. Thus, the emphasis in phytosanitary standards on technical soundness and analytical methods, allows the material to have substantial carry-over value that can often prove useful in a variety of situations where area-wide pest management may be an option.

In summary, it may be noted that the contemporary maxim, “think global and act local”, has special significance for area-wide pest management because it represents exactly the type of thinking that brings the concept into focus. Although not a panacea, it is clearly a powerful option when used in the proper circumstances and with the full
commitment and cooperation of implementing parties. As governments and growers become more aware of the economic and social benefits accruing from eradication or sustainable pest management over an extended period and area, the concept of area-wide pest management will become increasingly apparent and more attractive. Both the IPPC and the SPS Agreement are structured to accept and encourage area-wide pest management as a tool for promoting safe trade and contributing as much as possible to the complementary goals of food security and economic security for all countries.

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PART II.

APPLICATION OF AREA-WIDE CONCEPT TO NON-FRUIT FLIES

A) MEDICAL AND VETERINARY PESTS
Success in Zanzibar: Eradication of Tsetse


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INTRODUCTION

There are about 22 species of tsetse flies found nowhere else in the world except in 36 countries of sub-Saharan Africa. Tsetse flies transmit a debilitating and often fatal disease, trypanosomiasis, which causes tremendous losses of livestock, and severely limits agricultural production (it reduces output of milk and meat, causes mortality, infertility and abortion in livestock, deprives the rural population of draught power and manure to improve and increase crop production). Tsetse flies also transmit human trypanosomiasis, commonly known as “sleeping sickness”. It is estimated that over 55 million people living in rural sub-Saharan Africa are at risk from this fatal disease.

Tanzania’s Zanzibar Island is situated 35 km off the eastern coast and comprises two main islands, Unguja and Pemba. Previous surveys revealed that out of the seven tsetse species found on mainland Tanzania, only Glossina austeni Newstead infested Unguja Island. No tsetse fly was found on the island of Pemba. The fly is responsible for the cyclical transmission of trypanosomiasis in livestock, the causative agents being mainly Trypanosoma conglolense and, to a lesser extent, T. vivax. It is estimated that in Zanzibar, the disease causes annual losses of US$2 million. Since fly suppression by conventional techniques has often resulted in short-term success, Tanzania has always appreciated that the long-term solution to the trypanosomiasis problem is the eradication of tsetse flies in the country.

In 1994, the International Atomic Energy Agency (IAEA) and the United Republic of Tanzania embarked on a project with the objective of eradicating tsetse flies from Zanzibar Island by applying the sterile insect technique (SIT) (Dyck et al. 1995, in press). Previous tsetse eradication efforts in Tanzania using SIT, enabled the establishment of a modest capacity on tsetse mass rearing in Tanga (Williamson et al. 1983). The Zanzibar tsetse project was successfully completed in 1997. The estimated cost was US$7,941,000 but only US$5,788,097 was actually spent. Financial assistance came from international donors such as the governments of Belgium, Canada, China, Sweden, the United Kingdom and the USA. The results and achievements of the Zanzibar tsetse fly eradication project are presented in this paper.
MATERIALS AND METHODS

Fly Production

The Tsetse and Trypanosomiasis Research Institute (TTRI), Tanga, Tanzania, provided the sterile male flies for release. Tsetse mass rearing procedures used were those previously described (Nash et al. 1968, Tarimo et al. 1984 and Msangi et al. 1995, in press). Flies were held in three insectaries (insectary I holding 21 trolleys, and insectaries II and III holding 30 trolleys each). About 40 male and 200 female flies were put into a round PVC production cage (20 cm diameter). The cages with flies were put onto trolleys each capable of holding 98 cages. This gave the facility a holding capacity of 1,587,600 female flies. The fly holding room was maintained at 22-24°C and 70-80% relative humidity. Deposited pupae were collected daily, machine sorted and incubated in open trays. Emerging flies were automatically marked in the ptilinum by a Day Glo fluorescent dye for identification. Flies were fed daily on defibrinated bovine blood through a silicon membrane. In the handling room, flies were immobilised at 4°C for sex separation. Female and some male flies (20%) were retained to form colony flies. Male flies meant for release (80%) were fed twice before release, with trypanocide (samorin) added to their diet to prevent risk of disease transmission (Moloo and Kamunya 1987). The flies were chilled and placed in 0.5 litre thermos flasks, sterilised with 120 Gy, and put in small biodegradable release boxes at a rate of either 50 or 100 per box.

Improvements in Rearing Procedure Beneficial to Fly Production

No sex separation after mating

Female and male flies were no longer separated after mating. Instead, they were caged together immediately after emergence (day zero mating). This eliminated chilling, and minimised handling which produced better quality insects. In the method used previously, flies were chilled at 4°C twice for sex separation (i.e., before and after mating).

Mating ratio of 1 male : 5 females

Upon emergence, flies were transferred to production cages at a ratio of 1 male: 5 females (only 20% of all male flies produced were retained). This increased the number of male flies for release, saved space and diet. In the old method, flies were mated at a ratio of 1 male: 2 females (50% of all male flies being retained).

Bulk irradiation of males

About 3,000 - 7,000 chilled flies were put into chilled thermos flasks and irradiated at 120 Gy in a gamma irradiator- GC 220 of Co-60. This procedure saved a lot of time and labour. In the old method, 120-160 chilled flies were put into 4 small round cages and irradiated at 120 Gy in the old gamma irradiator - IBL 337 of Cs-137.
**Reduced membrane sterilisation time**

Membranes were heat sterilised in ovens at 120°C for six hours instead of overnight (more than 15 hours) sterilisation as done in the past. This procedure saved electricity consumption by 50%.

**Other important improvements**

These included training of staff in the most recent methods of rearing tsetse flies and refurbishment of the three insectaries. Equipment such as a large stand-by electricity generator for continuous power, pumps which drew water from a bored hole into a newly constructed water tank with a capacity of 15,000 litres for continuous water supply, two large walk-in freezer rooms for blood storage each with capacity of 10,000 litres, a clean air station (UV Hood) for checking blood contamination, computers for data processing, communication equipment, heating mats with thermistor thermostats to provide a stable temperature, timers to synchronise the operation of heating mats and ovens, electrical protection equipment, digital thermometers for monitoring chiller temperatures, were purchased.

For every shipment, a sample of the flies for release was taken in Tanga for quality assessment prior to plane take-off. The parameters assessed were the flying response, fly mortality, sexing error, induced sterility, fly marking, feeding status, etc.

**Fly Release**

The Commission of Agriculture and Livestock in Zanzibar, Tanzania, was responsible for the field operations involving fly release and monitoring. Fly suppression was done through an FAO project from 1988 to 1993, using topical application insecticides in areas with higher cattle density and insecticide impregnated screens in areas where cattle were scarce, such as in the large forested areas in the southern part of the island (Horeth-Bonntgen 1992). Releases of the sterile male flies started in 1991 with the release of adult flies on the ground in the Jozani forest as a pilot study (Vreysen et al. 1992) and terminated in July 1994. The aerial releases started in August 1994 in the southern half of the island and expanded to the whole island in mid-1996 when enough flies were produced. Flies were collected at the Tanga facility twice a week, using a light aircraft, and dispersed along the specific flight paths 1-2 km apart (Figure 1) at an altitude of 700-900 feet at a speed of 100-130 miles per hour.

**Fly Monitoring**

*G. austeni* population monitoring was performed with sticky blue-white leg panels (Vreysen et al. 1996). There were about 55 fixed monitoring sites (Figure 2) with over 500 sticky panels at any one time. Each site had at least 5 sticky leg panels to trap flies. The traps were inspected daily and replaced every week. All trapped flies were checked for the presence of fluorescent dye in their head capsules using UV microscopy to distinguish released, from indigenous flies. Wild female flies were dissected for assessment of their reproductive status.
Disease Monitoring

Disease monitoring was performed using parasitological techniques (PCV, MHCT and BCT). The entire Unguja Island was divided into 38 blocks (Figure 3) with over 1,000 sentinel cattle (about 2% of cattle population). Each block had a sentinel herd of 30-40 cattle to monitor the disease and were treated with Berenil at each collection (Pan et al. 1995, in press). Blood samples were taken every 2-5 months and examined for presence of the parasite. Animals found positive received an immediate treatment of Berenil.
RESULTS

Fly Production

In 1994, the *G. austeni* colony at TTRI remained below 50,000 female flies. It then rapidly increased to 400,000 at the end of 1995. By the end of 1996, the colony had reached close to 1 million female flies (Figure 4). The FAO/IAEA laboratory at Seibersdorf, Austria, shipped a total of 3,861,242 pupae with the objective of boosting the fly colony at TTRI. This was stopped in August, 1996 when the TTRI fly colony was able to sustain itself.

As the colony expanded, more flies were available for release. In 1994, slightly less than 20,000 sterile male flies were produced per week at TTRI. The production increased to 60,000 in 1995 and peaked at more than 100,000 in 1996 (Figure 5). During the project’s 4 years of operation, TTRI produced 24,115,332 pupae and from
these a total of 8,967,585 adult male flies (about 50,000 flies per week) were produced, sterilised and shipped to Zanzibar.

![Map of Zanzibar with sentinel cattle blocks](image)

Figure 3. Thirty-eight blocks each with 30-40 sentinel cattle.

Results from quality assessment showed an increase in quality. On average, more than 93% of all flies were able to fly, only 2.6% died and sexing error was 0.66%. Induced sterility and marking was 100% (Kitwika et al. 1997).

**Fly Monitoring**

For every flight, a sample of the flies for release was taken in Zanzibar to assess its quality. The data were compared with those taken at Tanga just before the shipment and indicated that the release operation did not seriously affect the quality of flies. Fly mortality increased by only 2% and proportion of non-fliers increased to 1.6% (Saleh et al. 1997).
Before suppression, the apparent fly density in the heavily forested areas (Jozani forest) was about 3.0 flies/panel/day. Suppression efforts in the island reduced the wild fly density by over 95%. Ground release caused little further reduction. The apparent density of the wild tsetse population on Unguja Island since the initiation of the aerial release programme is shown in Figure 6. In 1994, the wild fly apparent density was just below 0.1 flies/panel/day and was reduced further to below 0.01 flies/panel/day at the end of 1995. The population crashed at the beginning of 1996 with apparent densities of less than 0.001 flies/panel/day and the last wild fly was caught in September 1996.
Figure 6. Apparent density of wild *G. austeni* on Unguja Island.

The ratio of sterile:wild male flies trapped increased initially due to the increasing number of released sterile male flies per week and later due to a decline in the number of wild flies. For the year 1994 up to the first quarter of 1995, the ratio was below 10:1 (sterile/wild) and this ratio induced sterility in 26% of young females. A ratio of 20:1 caused further reduction in the wild fly population. During the last quarter of 1995, the ratio of 50:1 was reached and induced sterility in 72% of young females. A ratio of 100:1 ensured 100% induced sterility in all newly emerged females (Saleh et al. 1997, in press). One year after the ratio of more than 50:1 was obtained, the last wild fly was trapped on Zanzibar Island.

**Disease Monitoring**

In the northern half of Unguja, the disease monthly incidence was less than 0.1% for *T. congolense* and less than 0.4% for *T. vivax* when the project started in 1994. In 1997, the disease incidence was reduced to undetectable levels of *T. congolense* and occasional infections of *T. vivax*. In the southern half of Unguja, the monthly incidence was less than 1% for *T. congolense* and 2-4% for *T. vivax* when the project started in 1994. In 1997, the disease incidence was reduced to undetectable levels of *T. congolense* and the occasional infection of *T. vivax*. The disease incidence at the end of the project was, therefore, less than 0.1% and this was no longer a threat to cattle improvement.

**DISCUSSIONS**

During the early stages of the project, the fly colony at TTRI, was faced with several limiting factors such as, poor conditions of the insectaries, lack of continuous water supply for cleaning equipment, unstable rearing conditions due to irregular power supply and an inadequate quality blood diet. The improvements made were crucial to the production of sufficient sexually sterile male tsetse flies for the project. Efforts are ongoing, through the FAO/IAEA Coordinated Research Programme (CRP), to further
improve tsetse mass rearing procedures in order to increase the production capacity and quality of the flies.

The aerial release operation was efficient in dispersing flies (5% flies re-captured) especially to habitats that were difficult to reach and had very small effect on the quality of released flies. The ratio of more than 50 sterile:1 wild male was sufficient for the rapid reduction of the wild fly population. At such a high ratio, G. austeni was eradicated from Zanzibar Island within one year.

The decline in disease incidence suggested that released sterile male flies were not transmitting trypanosomiasis. It also suggested that released sterile male flies caused the decline and extinction of the G. austeni fly population on Zanzibar. Monitoring of both flies and disease in the absence of tsetse flies is currently in progress and the outcome will confirm the eradication of tsetse flies in the island.

ACHIEVEMENTS

The Zanzibar project strengthened TTRI’s capacity, both human and physical, for tsetse fly mass production and the use of SIT. The institute will play a vital role in the eradication of tsetse using SIT, where feasible, on mainland Tanzania. It also has the potential to assist other affected countries in the region.

The successful eradication of tsetse flies on Zanzibar Island created new opportunities for the Zanzibar farmers to enhance the mixed farming system which is considered the best way of achieving sustainable agricultural development and food security. Zanzibar farmers will be able to keep healthier animals as well as introduce more productive breeds. Zanzibar will no longer import trypanocidal drugs and insecticides, as well as animal products.

The success of the Zanzibar project has demonstrated SIT’s strong potential for African countries. It has given a new impetus to the fight against the tsetse fly not only in Tanzania but also in other affected countries.

REFERENCES


Success in Zanzibar: Eradication of Tsetse


Current Tsetse Control Operations in Botswana and Prospects for the Future

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INTRODUCTION

Several tsetse control methods have been used in Botswana over the past 70 years, ranging from bush clearing and selective game elimination, ground spraying with residual insecticides, aerial spraying with non-residual insecticides to the present odour-bait approach.

Sequential aerial spraying, initially with endosulfan or mixtures of endosulfan with one of the synthetic pyrethroids, effectively controlled tsetse but did not achieve eradication. Aerial spraying was suspended in 1991 when the tsetse population had been reduced to a relatively small population along the Linyanti and Kwando rivers bordering Namibia and to an area of 4,000-5,000 km² in the Okavango Delta.

After the 1991 aerial spraying operation the Tsetse Control Division switched to the use of odour-baited, insecticide-impregnated targets as well as localised, ground based thermal fogging.

There has been no incidence of human and bovine trypanosomiasis since the mid-1980s and no significant insect population recovery since targets were introduced.

THE CURRENT TSETSE SITUATION IN BOTSWANA (FIGURE 1)

Relatively little aerial spraying was carried out along the Linyanti and Kwando rivers, bordering the Namibian Caprivi Strip, between 1972 and 1991. Surveys carried out in May 1992, i.e., after the aerial spraying campaign, revealed a fairly widespread infestation and traps caught an average of 80 tsetse/day. The Division deployed and periodically re-treated a limited number of targets to provide some protection for government officers and armed forces operating in this extremely remote area. In 1995, 21 monitoring traps were deployed in the predominantly linear riverine habitat. The highest trap catch was 16 tsetse/trap/day and 16 of the traps caught no flies at all.

Patchy recovery has subsequently been reported by tour operators in the area but selective target deployment has continued and has kept this to a minimum.

Tsetse distribution in the Okavango Delta where the tsetse habitat is much more widespread, varied and fragmented has been more problematic. However, despite logistical problems, the situation remains under control.

Routine surveys increased over the past three years and tsetse have been confirmed throughout an area of about 5,000 km² in the northwest and central delta.

Until the late 1970s, the southwestern delta was a tsetse stronghold but over the past 20 years, the annual flood cycle has failed to reach the area and it has progressively dried out. Host animals such as buffaloes and elephants and many of the antelopes species are now scarce in the area and tsetse, removed by aerial spraying, remain absent.
The annual floods have continued to regularly irrigate the eastern delta and wildlife remains spectacularly abundant. To date, surveys have not revealed the presence of tsetse in this area either.

The northern central delta was never completely cleared of tsetse by aerial spraying and a patchy population still remains. Some areas with historically high tsetse densities such as Lopis Island, where survey teams would regularly catch over 200 tsetse per day in the late 1980s, were cleared by the aerial spraying and remain fly free. Other areas such as Mombo and Guai Island, which is only about 20 km away from Lopis, continued to catch large numbers of tsetse. Mombo became so bad in 1994 that tourists were complaining, and the Division considered the re-introduction of aerial spraying. One trap deployed by helicopter on the remote and virtually inaccessible Guai Island caught 2,500 flies after being in place for 20 days.

Assignment of a full time operational field team to the Mombo/Guai area in 1996 gradually expanded the deployment of targets and ensured reasonably frequent servicing intervals. The tsetse situation was subsequently brought under control (Figure 2).

Three other specific areas have been allocated to operational field units and these too have been kept under control.

Unfortunately the Division's resources, particularly transport, have not allowed any further concerted control efforts beyond these four assigned areas. Small resurgent populations around the periphery of the "known" tsetse distribution (Figure 3) have periodically been discovered and selective target deployment by a mobile support unit has dealt effectively with these. Recently, the Division has been assisted by private sector tour operators who have accepted responsibility for maintaining targets in the vicinity of their safari camps (Figure 4).
To date, tsetse have not been eradicated from any area since 1992, i.e., since the introduction of targets.

Figure 2. Mombo tsetse survey results.

Figure 3. Patchy tsetse distribution in the Okavango Delta (total area about 20,000 km² and infested area about 5,000 km²). Dark rectangle - high fly density limited to a very small area of a few hundred km²; grey rectangle - medium fly density; clear rectangle - low fly density. A low density of tsetse occurs on the northern border with the Caprivi.
Current Tsetse Control Operations in Botswana and Prospects for the Future

The areas allocated to Units 1-4 and to a private contractor are shown above. They amount to 6000 km$^2$ in total. In addition, small peripheral areas are infested by fragmented pockets of tsetse and these, shown in dark rectangles, are controlled jointly by the Tsetse Control Division and private tour operators.

Figure 4. Operational Control Areas.

TARGET DEPLOYMENT IN NORTHERN BOTSWANA

The Division deployed or re-serviced 20,000 targets in 1997 (Figure 5). During the same period, 10,000 target covers had to be replaced because they were damaged by wind, wildlife or fire. Elephant damage is particularly widespread and in 1997, accounted for 60% of the total damage. Target re-servicing is an ongoing process and the aim is to re-service targets at six monthly intervals. Lack of serviceable transport seldom enables the Division to achieve this aim thus some targets may be left for over a year. On an average, targets are re-treated about every 8 months and it is estimated that there are about 12,000-15,000 fully effective targets in the delta at any one time.
Figure 5. Distribution of targets deployed in the Okavango Delta.
(The exact location of each target deployed was determined by using the geographical positioning systems (GPS). The locations were archived in a geographical information system (GIS) Arc View.)

FUTURE PLANS

The aim of the Tsetse Control Division is to eradicate tsetse, using cost-effective, environmentally sensitive measures; thus the past few years have seen a progression from ground spraying to non-residual aerial spraying and finally to the odour-bait technique. Resources, particularly transport, are a problem and the government has recently approved collaborative ventures with the private sector to overcome these problems.

Two studies were recently completed with Department for International Development, United Kingdom (UK-DFID) support to assist the Division to develop a long-term control strategy to achieve the above aims:

- A socio-economic analysis of the implications of trypanosomiasis and tsetse control with particular reference to the possible involvement of private sector tour operators and local communities i.e., the primary beneficiaries (Mullins et al. 1997a, b).
- A preliminary study to develop environmental guidelines for staff handling insecticides or working in environmentally sensitive areas such as the Okavango Delta. A booklet on environmental guidelines was produced in English and Setswana (Grossman and Johnson 1997).
The eradication of tsetse is the current government policy but there is no indication that this will be achieved with the current control programme; indeed few, if any, other countries have actually eradicated *Glossina morsitans* using targets only. An internationally funded team under the auspices of the IAEA does appear to have eradicated *Glossina austeni* from Zanzibar Island after a programme of cattle dipping, target deployment and, finally, SIT.

There have been no cases of sleeping sickness or nagana in Botswana since the mid-1980s and provided that the tsetse distribution does not expand dramatically, there is every possibility that these diseases will remain under control. Thus the continuing presence of low fly densities will present nothing more serious than a “nuisance” problem.

However, maintenance of the *status quo* still requires a recurrent expenditure in excess of US$1.5 million per year. This may be partially defrayed by involving the private sector but full privatisation is certainly not envisaged at this stage. There are, nevertheless, compelling entomological and financial arguments for continuing the search for some means of eradicating tsetse from Botswana.

Should targets ultimately fail to achieve the government’s objectives, there is a strong case for supplementing the odour-bait technique with non-residual aerial spraying. This did not achieve eradication between 1972 and 1991 when it was essentially the sole technique employed. But technical advances have been made in recent years - notably with navigation aids - and in combination with targets, it may prove effective. There would be an environmental cost in the world's largest inland delta although past monitoring might suggest that any effects would be short-term only (Douthwaite 1992, Douthwaite et al. 1981, Everts et al. 1983, SEMG 1986, SEMG 1992). There might also be a shift in support from private sector tour operators who currently provide considerable assistance to the Division but who, in general, oppose a return to aerial spraying.

It remains the policy of the government and the Division to retain all options for the eventual elimination of tsetse flies from Botswana. This includes ground and aerial spraying, thermal fogging and SIT. On environmental grounds, the latter has considerable appeal.

In many ways, Botswana presents an ideal situation for the use of SIT to control or eradicate tsetse flies:

- There is only one species, which is at the limit of its natural distribution.
- The infested area is relatively small and discrete.
- After 20 years of aerial spraying, densities are very low in most areas.
- Possible lines of re-invasion from Angola, Namibia or Zambia are tenuous and should be easily defendable.
- The area is flat and therefore conducive to the aerial release of sterile males.
- Tsetse flies currently infest a cattle free area so there is no likelihood of large numbers of sterile flies temporarily raising the endemicity of trypanosomiasis.

On the down side, Botswana would need assistance from the IAEA but is not a member and membership would probably cost in excess of the recurrent TCD budget. There is currently no large colony of *Glossina morsitans centralis*. 