REFERENCES


Potential for Area-Wide Control or Eradication of Tsetse Flies in Africa

J.P. Kabayo¹ and U. Feldmann²

¹ Department of Biochemistry, Makerere University, Kampala, Uganda
² Insect and Pest Control Section, Joint FAO/IAEA Division, P.O. Box 100, A-1400 Vienna, Austria

INTRODUCTION

Tsetse flies (Glossina) are found in Africa over an area, estimated by various authors, of 7-11 million sq. km. The northern limit of this area corresponds closely to the southern edges of the Sahara and Somali Deserts, running along 14°N and extending across the continent from Senegal in the west to Somalia in the east. The southern limit of tsetse distribution corresponds closely to the northern edges of the Kalahari and Namibian Deserts in the west and runs generally at 20°-30°S to the east of the continent (Ford and Katondo 1977). This tsetse fly belt covers the following 38 countries (listed below) in which the tsetse flies spread African trypanosomiasis, a severe disease that affects man and his domestic livestock, and is among the factors responsible for limiting the pace and extent of development in those countries:

- Angola
- Equ. Guinea
- Liberia
- Sierra Leone
- Benin
- Eritrea
- Malawi
- Somalia
- Botswana
- Ethiopia
- Mali
- South Africa
- Burkina Faso
- Gabon
- Mozambique
- Sudan
- Burundi
- Gambia
- Namibia
- Tanzania
- Cameroon
- Ghana
- Niger
- Togo
- Guinea-Bissau
- Nigeria
- Uganda
- Chad
- Ivory Coast
- Rwanda
- Zambia
- Congo (Bra.)
- Kenya
- Senegal
- Zimbabwe
- Congo (Kin.)
- Lesotho

The disease is of a major economic importance. Throughout the affected countries within the fly belt, areas that are heavily infested by the tsetse fly are virtually devoid of cattle and other species of domestic livestock. Distribution of livestock in all countries on the African continent where densely infested foci exist is almost exactly the reverse of the distribution of the fly (Finelle 1974, Brunhes et al. 1994).

Attempts to control African trypanosomiasis date back to the beginning of this century. Several different methods of control, some aimed at the disease-causing organism and other aimed at the vector, were employed (Nagel 1995, Jordan 1986). Until after the Second World War, when insecticides became available for use in tsetse control campaigns, the most widely used control measure against tsetse flies was habitat destruction (involving felling trees and bush-clearing), the elimination of host animals (involving killing of wild game) and, to a certain extent, the use of various trapping devices to catch the flies. The tsetse control campaigns mounted in the 40s, 50s and 60s were invariably extensive “roll up the country” type of operations, planned and
executed military style. Tsetse control campaigns in many countries, including Nigeria, Uganda, Zambia, Zimbabwe, Rwanda and Kenya, succeeded in eliminating tsetse flies from large expanses of land.

The events that punctuated the political history of the African continent throughout the 60s and 70s, characterised by independence and liberation movements, took their toll on the gains and successes achieved earlier in tsetse eradication campaigns. The pre-occupation with the changes from colonial administration to self-rule over much of Africa affected the subsequent budgets, emphasis and management of tsetse control programmes. Where the tsetse control programmes had been managed by a single colonial authority, the situation changed at independence. The government of each country subsequently took charge of its own independent programme, making co-ordination of programmes and control methods difficult. Soon after many countries attained their political independence, variations in the priority each government attached to tsetse control began to emerge. Regional tsetse control authorities and research institutions which were shared between several countries were destroyed. Human and material resources were divided and spread thin in a new trend of prestige, pride and political expediency to create new national facilities and, in effect, to “nationalise” tsetse flies.

PRELUDE TO RE-INVASION

Countries which attained political independence and became involved in tsetse and trypanosomiasis control activities pursued an approach which stressed political boundaries and national sovereignty lost the opportunity to merge the fragmented efforts of individual countries. The differences which existed in the affected countries at independence reflecting the approach followed by the colonial governments also became “nationalised” and became preserved within the respective political boundaries. For example, many of the countries which were colonised by the British used trypanocidal drugs widely, but conducted large vector control programmes as well, while the countries which were colonised by the French relied exclusively on the use of trypanocidal drugs to control trypanosomiasis (Jordan 1986).

Then came a period, leading to the present times, which was characterised by political instability and other civil disturbances. These combined to precipitate the present critical situation of increased levels of tsetse fly infestation and high disease incidence. Over the years the confident, vigilant efforts and emphasis aimed at eradication of the disease were replaced with supposedly more “realistic” goals of control. This control was subsequently modified and rephrased as integrated control, shifting to containment, then, more recently, sinking to the resigned objective of simply management of the disease. In spite of national efforts and injections of donor support in every country, little success has been recorded and it is increasingly becoming clear that a new approach needs to be designed.

AREA-WIDE APPROACH

As in campaigns against other insect-borne diseases, the major attraction to the approach to stop transmission of the disease by eradication of Glossina spp. is its economic advantages over the control approach. Whatever the cost of eradication may be, eradication is a time-limited, once-and-for-all cost, while the costs involved in
control measures recur indefinitely. As stated above, eradication had been achieved in large parts of the continent, but most of these became re-infested, because the areas had not been sufficiently protected from re-invasion and lacked the necessary post-eradication surveillance. The lesson that can be drawn from this experience, however, is that it is inappropriate to initiate a control campaign in the middle of a tsetse-infested area. In countries, such as Zimbabwe, where an effective tsetse control capability exists and where large areas have been reclaimed, the long border perimeter involved demand regular treatments to control re-infestation.

Experience has shown that protection of even small areas, e.g., ranches, stock farms and settlement areas located within a major fly belt, by regular application of insecticides or by any other method or combination of methods is uneconomical, especially with increasing costs of labour and materials. The only viable approach, therefore, is to tackle large areas, preferably covering the entire infestation or in sections which are isolated from each other, e.g. by natural boundaries where no re-invasion is possible. This area-wide approach to tsetse control would represent a major departure from current practice where control is confined within the political boundaries of individual countries. There have been several attempts to control various insect-borne diseases on an area-wide basis, examples of which would illustrate the wisdom and advantages involved. Probably the biggest, albeit unsuccessful, programme ever mounted on the African continent was the attempt in the 1960s to eradicate the malarial mosquito. More recently, the West African onchocerciasis control programme brought together 11 countries in a collective fight against black flies which transmit onchocerciasis and succeeded to reduce drastically its incidence and threat to the population. In 1991, government representatives from Brazil, Paraguay, Uruguay, Bolivia, Argentina, Chile and Peru adopted a resolution calling for action to eradicate Triatoma infestans, the insect which spreads Trypanosoma cruzi, and the parasite causing Chagas disease (Kingman 1991).

The seven South American countries set up an intergovernmental commission for the Chagas disease, to raise and administer funds and co-ordinate the implementation of the eradication plan. The plan was to spray every home in all areas known to be infested with T. infestans in a big programme covering parts of Argentina, Brazil, Chile, Bolivia, Uruguay, Paraguay and Peru and included follow-up inspections and evaluation to ensure that the insect did not return. In another area-wide control programme, the USA and the countries of South America employed the sterile insect technique over the entire area to eradicate the New World screw-worm fly. Earlier eradication programmes in the USA alone had failed because of re-invasion from infested areas in the neighbouring countries.

NEW FORMS OF ORGANISATION

There is need to create an African-wide organisation similar in structure and function to the South American Commission on the Chagas disease. The following can then be studied:

- The differences currently existing in the level of the priority placed on tsetse and trypanosomiasis control in different countries.
- The need for co-ordination and synchronisation of control operations and the rationale behind the need to exploit natural boundaries in the context of preventing re-infestation of cleared areas.
The need for an African-wide framework of handling trans-boundary infestations.

The need to pool resources, avoid duplication and relate to questions of economies of scale.

The need to agree on methodologies and choice of control strategies.

The need to better marshal and manage resources for control programmes with emphasis on coherence and accountability.

The need to direct all available resources with emphasis on the execution of actual control programmes with dates and deadlines.

The need to preserve a level of continuity to counter the effects of various disruptions on control programmes.

The need to translate African political rhetoric on unity to the reality of united action to solve a common problem.

The need, generally, to create a mechanism that will emphasise and enhance the true nature of tsetse and trypanosomiasis as an Africa-wide problem requiring an Africa-wide approach.

The Organisation of African Unity should take up the challenge to mediate in the formation and rationalisation of the proposed Africa-wide Commission on tsetse and trypanosomiasis.

CONCLUSION

The tsetse and trypanosomiasis problem is an Africa-wide problem which needs an Africa-wide approach.

The most viable form of organisation successfully adopted to handle similar problems elsewhere in the world is the creation of a single organisation to manage and co-ordinate future tsetse and trypanosomiasis control programmes.

REFERENCES


Screw-worm Eradication in the Americas -- Overview

John H. Wyss
USDA, APHIS, International Services, Panama City, Panama

INTRODUCTION

Screw-worms [Cochliomyia hominivorax, (Coquerel)] are found only in the Americas, and are known, therefore, as the New World Screw-worm (NWS). The larval stages of the fly feed on the living flesh of their host. A screw-worm infestation can kill an adult animal in 7-10 days if not treated. All warm-blooded animals are affected including man.

Although screw-worms had long been recognised as a severe pest of animals in the southwestern United States, they had never been detected east of the Mississippi River before 1933. In July 1933, screw-worms were transported on infested cattle to Georgia and became established east of the Mississippi River. Screw-worms spread quickly in the southeastern United States and were able to overwinter in southern Florida. Being new to the region, they were quickly recognised as a severe pest with a tremendous economic impact on livestock production. The livestock owners in the southeastern United States immediately noticed an increase in the number of animal deaths and increased costs of insecticides, veterinary medicines, veterinary services, inspection and handling. At the same time, they observed a decrease in animal weights and in milk production. Due to these observations, the livestock industry in the southeastern United States requested help in controlling screw-worms. Because of these requests, the research community became interested in control and eradication measures for this pest.

Early work by Crushing and Patton in 1933 recognised that C. hominivorax was an obligatory animal parasite and different from the secondary blowfly, Cochliomyia macellaria (Fabricius). In 1934, the United States Department of Agriculture (USDA), Agricultural Research Service (ARS) opened a research station in Valdosa, Georgia, and E.W. Laake and E.F. Knipling were assigned to work there. In September 1935, R.C. Bushland was hired by ARS to do research related to screw-worms at an ARS Research Laboratory in Dallas, Texas. Melvin and Bushland in 1936 developed artificial media and techniques for screw-worm colonisation. In 1937, Knipling and Bushland began discussing an autocidal theory of screw-worm population suppression. These workers and others were studying screw-worms and developing treatment and control measures, but all work was suspended in 1937 because of the Second World War. Following the war, in 1947, interest once again turned to screw-worm control and eradication, and the development of what would become the sterile insect technique (SIT). Muller in 1950 described the effects of X-ray exposure on the reproductive system in Drosophila. Bushland and Hopkins in 1951 demonstrated that adult screw-worms of both sexes were sexually sterilised by irradiating the pupal stage of the insect. This promising work was field tested twice between 1951 and 1953 on Sanibel Island. Sanibel Island is a small island with an area of only 36 km\(^2\) located 3 km off the southeast coast of Florida. In these first tests, 38 sterile males were used per km\(^2\) on a weekly basis. The sterile flies were produced in the ARS Laboratory located at...
Kerrville, Texas. The results of the last field test were very encouraging. Sterile egg masses were detected the first week and within several weeks, 80 percent of the egg masses collected were sterile and the number of egg masses declined. The experiment was continued for several months, but screw-worms were not eradicated. This discouraging outcome was explained by the premise that the migration of fertile flies from the mainland was causing continuous re-infestations of the island. In 1954, this premise was tested in Curacao, West Indies. Here was an opportunity to test the sterile insect technique (SIT) on a 440 km² island located 65 km from the mainland of South America. On this island, they doubled the number of sterile males released from 38 to 76 per km² on a weekly basis. The sterile flies used in this experiment were produced at the facility at Bithlo, Florida. The results of this field test were very good. Sterile egg masses were detected the first week; within several weeks, 84 percent of the egg masses collected were sterile and the number of egg masses was declining. Within several months, 100 percent of the collected egg masses were found to be sterile. This experiment was a complete success; the island of Curacao was determined to be screw-worm-free in 1954.

**Screw-worm Eradication Programme in the Southeastern United States (1957-1959)**

The success of the screw-worm eradication experiment on the island of Curacao in 1954, with the findings of Lindquist in 1955, that even under good conditions, there were no more than a few hundred screw-worm flies per square mile, led people to believe that screw-worm eradication was indeed feasible. In the spring and summer of 1957, livestock owners experienced the worst losses from screw-worms since their introduction into the southeast in 1933. This same summer, Bushland and his group of researchers conducted a pilot field test with sterile screw-worm flies covering 5,180 m² near Bithlo, Florida. In this field test, there was a 70 percent reduction in the number of cases in the centre of the test area. This result led to the implementation of an eradication programme in the southeastern United States. The programme began in 1957 and got off to a good start because the winter of 1957-1958 was one of the coldest and wettest in the history of Florida. To take advantage of the severe winter, sterile fly production at the Bithlo, Florida, facility was increased from 2 million per week to 14 million per week. The new sterile fly facility located near Sebring, Florida, was officially opened on 10 July 1958, and within 3 months, was producing over 50 million per week. The capacity of this new facility was 75 million per week. The last two cases detected in the southeastern United States occurred on 19 February 1959 and 17 June 1959. Sterile fly dispersal continued over the area until November 1959. No more cases were detected and except for imported non-replicating infestations, the southeastern United States has been free of screw-worms since that time.

**Screw-worm Eradication Programme in the Southwestern United States (1962-1966)**

Livestock producers in the southwestern United States watched the eradication efforts in the southeastern United States with much interest. The Southwest Animal Health Research Foundation (SWAHRF) was formed to obtain support for a screw-worm eradication programme in the southwestern United States. From 1960 to 1962, SWAHRF struggled to get a screw-worm programme authorised and to raise producer-contributed funds. In February 1962, authorisation was obtained for the programme.
Once authorised, the Animal Disease Eradication Division of the USDA expanded an existing rearing facility in Kerrville, Texas. Between February and June 1962, SWAHRF constructed a new screw-worm rearing facility at Mission, Texas. Vice-President Lyndon B. Johnson dedicated the new Mission, Texas, Screw-worm Rearing Facility on 16 June 1962. The new Mission facility had a capacity of 200 million sterile flies per week. With the facility now operational, the screw-worm eradication programme was ready to begin in the southwestern United States. The states of Texas and New Mexico were declared screw-worm-free in 1964, and the eradication programme was then expanded into Arizona and California. The entire United States was declared screw-worm-free in 1966. The plan at that time was to maintain a sterile fly biological barrier, by carrying out weekly dispersals of sterile flies along much of the border between the United States and Mexico, to prevent the migration of fertile flies from Mexico back into the United States. In addition, animals were inspected and dipped before entering the United States from Mexico. Despite these efforts, cases continued to occur in the United States. In 1972, there was a screw-worm outbreak in the United States that approached pre-eradication levels. There were also some cases in Texas in 1976 and 1978. The last autochthonous screw-worm case reported in the southwestern United States occurred in August 1982.

**Screw-worm Eradication Programme in Mexico (1972-1991)**

Due to these continued outbreaks and the interest of Mexican livestock producers in extending the eradication programme into Mexico, it was decided to move the barrier south to the Isthmus of Tehuantepec in Mexico. This location would be more economical (a 190 km width as compared to 2,400 km at the United States-Mexico border) to maintain. In addition, a barrier farther from the US border would afford more protection for the United States. An agreement was signed on 28 August 1972, to form the Mexico-United States Commission for the Eradication of Screw-worms (Commission). The objectives of the Commission were to construct and operate a sterile screw-worm fly production plant, and to eradicate screw-worms southwards to the Isthmus of Tehuantepec, in southern Mexico. The eradication programme got underway in 1972, using sterile flies produced in the plant at Mission, Texas. The Commission production plant was constructed in Tuxtla Gutierrez, Chiapas, Mexico, and was inaugurated on 28 August 1976, by the Secretaries of Agriculture from the United States and Mexico. The Tuxtla Gutierrez plant had the capacity to produce 500 million sterile flies per week. The eradication programme continued using sterile flies from both the Mission and Tuxtla Gutierrez plants until the Mission plant was closed in 1982. The Commission's objective, of eradicating screw-worms to the Isthmus of Tehuantepec, was achieved in 1984. However, the barrier at the Isthmus of Tehuantepec divided the country, with livestock producers to the south claiming the Mexican government was showing favouritism to producers north of the barrier. Further studies showed that Panama was a much better site for a permanent biological barrier. A barrier extending from the Panama Canal to the border with Colombia would require only 40 million sterile flies per week, compared to 150 million per week needed at the Isthmus of Tehuantepec in Mexico. In addition, in the eastern half of Panama, the movement of livestock is significantly less, when compared to the animal movements at the Isthmus of Tehuantepec in Mexico.
Screw-worm Eradication Programme in Central America

Following indications of interest in screw-worm eradication from all the Central American countries and Panama, a plan was developed in 1985 to extend the Screw-worm Eradication Programme through Central America and establish a permanent biological barrier in the eastern half of Panama. The first step in expanding the eradication programme to Central America was to enlarge the programme in Mexico to cover all of the country. Mexico was declared screw-worm-free on 25 February 1991. After eradication, Mexico had two screw-worm outbreaks, one in January 1992, and another in June 1993. The last screw-worm case in Mexico was collected on 17 June 1993, and no screw-worm cases have been detected since.


The Commission signed an agreement with the Guatemala Ministry of Agriculture, Livestock and Food (MAGA), on 10 December 1986, to eradicate screw-worms from Guatemala. A programme office was established in Guatemala City in 1988. Aerial dispersal of sterile flies over the large northern state of Peten started in September 1988. The area dispersed was extended until the entire country was covered by January 1991. At the peak of dispersal, approximately 115 million flies per week were being dispersed over Guatemala. Case numbers reached a maximum of 10,573 in 1988 and decreased each year afterwards. The numbers are biased on the low side because field surveillance activities did not commence in the southeastern part of the country until well after the number of cases in the north had already started dropping because of sterile fly dispersals. The last autochthonous screw-worm infestation in Guatemala was recorded on 10 May 1992: Eight introduced infestations were found later in 1992 at the Playitas Inspection Station, one of a number of inspection stations situated near the borders with Honduras and El Salvador on main livestock transportation routes. Two additional imported cases, one in February and one in April 1993, were found at the same inspection station. The number of flies dispersed was decreased starting with the northern state of Peten until, from January through June 1993, an average of only 41 million sterile flies per week was dispersed. The number of flies dispersed continued to decrease until all dispersals ceased at the end of December 1993. An official declaration of freedom from screw-worms was held on 20 May 1994. The programme office was closed on 30 June 1994.

Belize (1988-1994)

The Commission signed an agreement with the Belize Ministry of Agriculture and Fisheries (MAF), on 2 August 1988, to eradicate screw-worms from Belize. The programme office in Belmopan was dedicated on 25 August 1989. Dispersal of sterile flies began over the northern 40 percent of the country on 26 August 1989. Total coverage of the country with sterile flies was achieved on 10 April 1990. Screw-worm case numbers reached a high, after the programme began, of 172 cases in 1989, and declined each year thereafter. These numbers are also biased on the low side, because sterile fly dispersal started in the north, where the majority of cattle are found, nearly 3 months before all field inspectors were hired, trained and provided with transportation. Interviews with livestock producers indicated that much higher numbers of screw-worm infestations had occurred prior to the start of dispersal. At the peak of dispersal, an
average of 24 million sterile flies per week was dispensed. The last autochthonous screw-worm infestation was collected on 1 July 1991. No cases have been found since then. Dispersal of sterile flies over the northern half of the country ceased on 1 June 1992 and all dispersals ceased on 31 December 1992. The country was officially declared screw-worm free on 22 May 1994. The programme office was closed 30 June 1994.


The USDA signed a bilateral agreement with the El Salvador Ministry of Agriculture and Livestock (MAG), on 24 July 1991, to eradicate screw-worms from El Salvador. A programme office had already been opened in San Salvador and field surveillance activities initiated, resulting in an early start on obtaining data on the number of screw-worm infestations. Aerial dispersal of sterile flies over the entire country started in October 1991. At the peak of dispersal, an average of 24 million flies per week was being dispersed. A maximum of 800 cases in 1 month occurred in December 1991, and then declined each month thereafter. A small number of infestations was detected after March 1993, and only two infestations occurred in 1994. One, in January, was autochthonous and another, in May, was an imported case. No cases have occurred since. All dispersal of sterile flies ended in July 1994. An official declaration of freedom from screw-worms was held on 19 June 1995. The programme office closed on 30 June 1995.

**Honduras (1991-1996)**

The USDA signed a bilateral agreement with the Honduras Secretariat of Natural Resources (SRN), on 26 July 1991, to eradicate screw-worms from Honduras. A programme office was opened in September 1991, in Tegucigalpa. Field surveillance activities were initiated in the southwestern half of the country shortly afterwards. Sterile fly dispersal over the southwestern half of the country began in November 1991. The area of dispersal was increased until 100 percent of the country was being dispersed by June 1993. At the peak of dispersal, 120 million flies per week were dispersed. The area of dispersal began decreasing from the southwestern part of the country in June 1993 at about the same time that dispersal started in the eastern-most part of the country. Only about 33 percent of the country was dispersed in the first half of 1995. Beginning in July 1995, the dispersal area was further decreased to about 16 percent, dispersing only in areas adjacent to the border with Nicaragua. All dispersal of sterile flies in Honduras was terminated on 30 September 1995. The number of screw-worm infestations found peaked in 1992, and decreased each year thereafter. The number of cases detected was also biased on the low side, because country-wide surveillance did not commence until well after the number of cases in the southwestern half of the country had markedly decreased because of programme activities. The last case in the country was collected on 10 January 1995, and Honduras was declared screw-worm-free on 6 August 1996. The programme was essentially closed down with the exception of a small contingent to maintain screw-worm prevention and surveillance activities.

The USDA signed a bilateral agreement, on 26 November 1991, with the Nicaragua Ministry of Agriculture and Livestock (MAG) to eradicate screw-worms from Nicaragua. A programme office was opened in May 1992, in Managua. Countrywide field surveillance began in July 1992. The number of screw-worm infestations reported peaked in 1993 and declined each year thereafter. The largest number of cases occurred in June 1993, in which 3,595 were reported. Dispersal of sterile flies over the northern half of the country began in July 1993, and 100 percent coverage was achieved in July 1994. Approximately 120 million flies per week were required to disperse over the entire country. Following the beginning of sterile fly dispersal, the number of infestations countrywide dropped markedly. Only 137 cases were reported in March 1995. Dispersal over 100 percent of the country continued until January 1996, when dispersal in the northern one-third of the country was stopped. The last case in Nicaragua was reported on 1 June 1997. The plan is for Nicaragua to be declared screw-worm-free before the end of 1999. Programme activities will continue at a much lower level to maintain a critical level of screw-worm prevention and surveillance activities and provide dispersal centre services for Costa Rica.


The USDA signed a bilateral agreement with the Ministry of Agriculture and Livestock (MAG) on 29 November 1993, to eradicate screw-worms from Costa Rica. The screw-worm programme office opened in June 1995, in San José. Sterile fly dispersal over the northern part of the country began in April 1996, using flights operating out of Nicaragua. Dispersal of sterile flies, all from Nicaragua, over 100 percent of the country was achieved in October 1996. Approximately 60 million sterile flies per week were needed to cover the entire country at the programmed rate. Field surveillance activities began in April 1997. Because of the delay in beginning field operations, the number of reported screw-worm cases is relatively low. Currently (April 1999), the last reported case occurred on 18 March 1999.

Panama (1997-2000)

The USDA signed a bilateral agreement with the Ministry of Agriculture and Livestock Development (MIDA), on 11 February 1994, to eradicate screw-worms, construct and operate a sterile fly production facility and establish a permanent biological barrier in Panama. The regional screw-worm programme office in Mexico was relocated to Panama in July 1997, and field surveillance activities began in June 1998. Dispersal of sterile flies over approximately 12 percent of the western part of country began in July 1998, using over-flights out of Nicaragua. In October 1998, 50 percent of the country was dispersed from a new dispersal centre located at Tocumen International Airport near Panama City. Approximately 80 million sterile flies per week will be needed to cover the entire country at the programmed rate of 3,000 sterile flies per km² dispersed in 3.2 km swath widths.

Plans call for the construction of a new sterile fly production plant east of Panama City near the Pacora River on the land of the old Filipillo sugar refinery. A new plant would permit the current plant near Tuxtla Gutierrez, Chiapas, Mexico, to be closed. That plant has been in continuous operation 24 hours per day, 365 days per year since 1976. The costs of operating and maintaining that plant are steadily increasing.
The cost of aerial transportation of pupae from Tuxtla Gutierrez, Mexico, to dispersal centres in countries where the programme is operating is increasing as the distance from the plant to dispersal centres increases. The danger of fertile flies escaping from the plant in Mexico that is located so far inside the eradicated area is an ever-increasing concern.

ECONOMICS OF SCREW-WORM ERADICATION

Although screw-worm eradication is an expensive undertaking, the benefits of eradication justify the costs. The economics of living with screw-worms and the benefit to cost ratio of eradication are important factors in selling an eradication programme to foreign officials.

In 1996, the annual producer benefits in the United States, Mexico, and Central America were 796 million, 292 million, and 77.9 million US dollars respectively. These benefits were derived from decreases in death losses, decreases in veterinary services, veterinary medicines, insecticides, inspections, and handling costs and increases in meat and milk production. These producer benefits have an additional positive effect on the general economy of each country, and the region in general, due to the forward and backward linkages in the economy. This multiplier effect is estimated to be 3.5. The estimated total effect on the general economy of producer benefits is, therefore, estimated to be US$2.8 billion for the United States, US$1.0 billion for Mexico, and US$272.6 million for Central America. In addition, it is estimated that consumer benefits are equal to the effects on the general economy of the producer benefits. Adding this to the annual producer benefits results in a significant beneficial overall effect on the economy of all the countries that are now screw-worm-free.

The benefits to perpetuity for the annual producer benefits were calculated at 3, 6, and 8 percent discount rates. While the 8 percent rate represents the true cost of money, it is customary to use 3 percent for public-good programmes such as screw-worm eradication. The benefits to perpetuity for the producer benefits are US$26.5 billion for the United States, US$9.7 billion for Mexico, and US$2.6 billion for Central America, using the 3 percent discount rate.

The benefits to perpetuity are used to calculate the benefit to cost ratio for the screw-worm eradication programmes. The benefit to cost ratios for the eradication programmes have ranged from an average of 12.2 for Central America to 18 for the United States and Mexico. Even the smaller number is very supportive of an eradication programme.

In addition, screw-worm eradication has a significant human and wildlife health component that has not been included in the above figures.

FUTURE SCREW-WORM ERADICATION PROGRAMMES

All Central America is expected to be free of screw-worm infestations by the end of the year 2000. The Caribbean region is the next most logical area to eradicate this pest. Of all the Caribbean Islands, only Cuba, Hispanola (Haiti and Dominican Republic), Jamaica, and Trinidad-Tobago are infested with screw-worms. Their proximity, with the exception of Trinidad-Tobago, to the United States, Mexico, and Central America makes them a possible source of re-infestation for the screw-worm-free countries. The feasibility of expanding the eradication programme to the Caribbean
is very realistic. The Food and Agriculture Organisation (FAO) has done considerable work in the Caribbean and South America on the distribution of screw-worms. The International Atomic Energy Agency (IAEA) has been working with Jamaica for the past two years on developing a screw-worm eradication project. In May 1998, IAEA, Jamaican officials, and representatives of Mexico and the United States, individually, and the Mexico-United States Screw-worm Commission met and agreed to enter into a Memorandum of Understanding to cooperate on the Jamaican eradication project.

In South America, the economic benefits to livestock producers and consumers, and the general effect on the economies of the countries, would be very significant and would strongly support the idea of a South American screw-worm eradication programme. I personally believe that such an eradication programme is feasible and realistic. However, such a large undertaking would require a strong long-term political and financial commitment on the part of all the South American countries, and would necessitate coordination and an extreme dedication to work in harmony. It would not be easy; if it were, it would have already been done.

ACKNOWLEDGEMENTS

I would like to acknowledge the support and work of all the government officials, Commission and programme employees, livestock owners, and the general public of all the countries involved. The screw-worm programme, to be the success it has been, required the cooperation of all of these individuals and groups within a country, as well as cooperation between all the countries involved.

REFERENCES

The New World Screw-worm as a Pest in the Caribbean and Plans for its Eradication from Jamaica and the Other Infested Caribbean Islands

George H. Grant1, J. Wendell Snow2 and Moises Vargas Teran3

1 Veterinary Services, P.O. Box 309, Hope Gardens, Kingston, Jamaica
2 International Atomic Energy Agency, P.O. Box 100, A-1400, Vienna, Austria
3 FAO Division, Ministry of Agriculture, P.O. Box 309, Hope Gardens, Kingston, Jamaica

INTRODUCTION

The screw-worm, Cochliomyia hominivorax (Coquerel) (NWS), was eradicated from the Caribbean island of Curacao in 1964 (Baumhover et al. 1955). This programme was considered as a test of the SIT principle. In 1959, the pest was eradicated from Florida with the concept fully established as a sound and novel entomological principle (Baumhover 1966). In 1962, a similar programme was initiated in the southeastern United States with a barrier established along the Mexican-United States of America border (Bushland 1975). In 1975, the pest was eradicated from the island of Puerto Rico, the United States of America (US) and the British Virgin Islands (Williams et al., 1977). In 1981, the pest was totally eradicated from the US and in 1986 from all of Mexico.

It has since been eradicated from Belize, Guatemala, Honduras, El Salvador and Nicaragua. The eventual goal of the programme is to eradicate the pest from Costa Rica and Panama down to the Derail Gap where a sterile fly barrier will be maintained.

In the Caribbean, an estimated 86% of the land mass is considered infested by the New World screw-worm. Jamaica, Hispaniola, Cuba, Trinidad and Tobago are the countries known to be infested. Despite this fact, no comprehensive plans have ever been made for its eradication from these countries which together have a total livestock population of well over 16 million (Table 1). However, based on the great success of the programme elsewhere and recent interest shown by various international organisations and governments in countries which are infested, the situation is changing rapidly. Currently, the country which is most prepared for an eradication programme is Jamaica where government officials have long shown an interest in eradicating the pest. For example, in 1959, a group of Jamaican livestock owners visited officials associated with the Florida eradication programme. Since this date, serious consideration has been given and several attempts made by Jamaica to implement an eradication programme but without success. Real progress was not made until 1997, based principally on efforts by the Jamaican Veterinary Services Division (VSD) when cooperation was established with the International Atomic Energy Agency (IAEA), the Food and Agriculture Organisation (FAO) and the Animal and Plant Health Information Service of the United States Department of Agriculture (USDA/APHIS/ARS) with respect to the preparation for an eradication programme. Preliminary organisational activities for this programme have been started with the expectation that the first sterile fly releases will be made in January, 1999 to initiate what is projected to be a 3-year eradication campaign.
With respect to the rest of the Caribbean, FAO currently has a project in Cuba which is aimed at determining the extent of the problem and its economic impact. Concurrently, IAEA is developing a “thematic” plan for the entire Caribbean as well as South America.

Table 1. Current livestock population of the NWS endemic countries in the Caribbean (‘000’).

<table>
<thead>
<tr>
<th>Country</th>
<th>Beef Cattle</th>
<th>Dairy Cattle</th>
<th>Horses</th>
<th>Donkeys /Mules</th>
<th>Sheep</th>
<th>Goats</th>
<th>Water Buffaloes</th>
<th>Pigs</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuba</td>
<td>4,020</td>
<td>480</td>
<td>580</td>
<td>37</td>
<td>310</td>
<td>95</td>
<td>-</td>
<td>1,550</td>
<td>7,072</td>
</tr>
<tr>
<td>Dominican Republic</td>
<td>1,836</td>
<td>250</td>
<td>329</td>
<td>279</td>
<td>135</td>
<td>570</td>
<td>-</td>
<td>950</td>
<td>4,349</td>
</tr>
<tr>
<td>Haiti</td>
<td>1,055</td>
<td>145</td>
<td>400</td>
<td>290</td>
<td>85</td>
<td>910</td>
<td>-</td>
<td>360</td>
<td>3,245</td>
</tr>
<tr>
<td>Guyana</td>
<td>163</td>
<td>27</td>
<td>2</td>
<td>1</td>
<td>130</td>
<td>79</td>
<td>-</td>
<td>50</td>
<td>452</td>
</tr>
<tr>
<td>Jamaica</td>
<td>347</td>
<td>53</td>
<td>4</td>
<td>33</td>
<td>4</td>
<td>440</td>
<td>-</td>
<td>210</td>
<td>1,091</td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
<td>48</td>
<td>7</td>
<td>1</td>
<td>4</td>
<td>14</td>
<td>52</td>
<td>9</td>
<td>48</td>
<td>183</td>
</tr>
<tr>
<td>Suriname</td>
<td>89</td>
<td>10</td>
<td>-</td>
<td>-</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>38</td>
<td>156</td>
</tr>
</tbody>
</table>

Source: FAO 1996 Report
Data Banks of Trinidad and Tobago, Guyana, Jamaica

CUBA

This is the largest NWS infested country in the Caribbean with a landmass of approximately 114,525 km² and a human population of 10,870,000 people. An eradication programme for Cuba will require about 150 million sterile flies per week for two years. Similarly, in the case of this country, a full year would most likely be needed to organise the programme, two years for actual eradication and about one year for verification of results. It is possible that the eradication programme for the country could be carried out in two sections which would take longer but requiring fewer sterile flies at one time. The cost of eradication would likely to be somewhat higher if the 2-phase approach were to be selected. A one-step approach would incur additional costs based on the need for more emergence chamber space for flies. On the other hand, it would reduce the time needed for the eradication while at the same time reducing the need for quarantine and excluding the need for a buffer zone.

The cost-benefits from eradication have not yet been determined for Cuba but this work is currently being undertaken through the sponsorship of FAO. The current information is that sufficient data have already been collected to establish that the NWS is a serious problem in the country and that the insect is widely distributed throughout and affects all warm blooded species while being active at all seasons of the year. The
cost of implementing an eradication programme for Cuba is being estimated at some US$54 million (Table 2).

Table 2. Estimated cost of eradicating the NWS from Cuba.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>ESTIMATED COST US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterile Flies (estimated at 1,700/million for 2 years)</td>
<td>26,000,000</td>
</tr>
<tr>
<td>Chilled Fly Chambers for Fly Emergence</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Information Campaign</td>
<td>4,000,000</td>
</tr>
<tr>
<td>Quarantine Campaign</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Administration</td>
<td>3,000,000</td>
</tr>
<tr>
<td>Dispersal Centre Operation</td>
<td>12,000,000</td>
</tr>
<tr>
<td>Miscellaneous Costs</td>
<td>4,000,000</td>
</tr>
<tr>
<td>Field Operations</td>
<td>7,000,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td>54,000,000</td>
</tr>
</tbody>
</table>

HISPANIOLA

Hispaniola, which comprises both Haiti and the Dominican Republic, is considered an infested area. Both countries occupy an equivalent landmass of 10,710 km² each and with human populations of 6,764,000 (Haiti) and 7,471,000 (Dominican Republic). The populations of both countries are reported to be fast growing with an expected increase of 1.5 million within the next 10 years. The best estimates of NWS damage at this time (FAO) are US$16 million and US$10 million annually in the Dominican Republic and Haiti respectively. In both countries, there is currently no organised effort to control the pest. While the NWS is well known to local people, the problem is believed to be either ignored or neglected by the local authorities. It is suspected that once the relevant impact studies are conducted, the greatest losses to the livestock industry and the biggest human health problem resulting from NWS infestation anywhere may well be found in these two countries.

Similarly, despite the current difficulties, these two countries may well be the most important for eradication to take place at this time in the region. It is being suggested that the best approach to the implementation of an eradication programme for these two countries is the use of a combined programme utilising a single distribution centre for both.

The estimated requirements for such a programme is about 95 million sterile flies weekly and at a total cost of almost US$36 million (Table 3). The time frame would be similar to that for Cuba.

SOUTH AMERICA AND TRINIDAD AND TOBAGO

The landmass associated with the NWS in South America is very large. The literature contains numerous reports of infestations in Columbia, Venezuela, Suriname, Guyana, French Guyana, Ecuador and Paraguay. There are literature reports of human infestations in Uruguay, Peru and Bolivia. The temperatures in the southern regions of Argentina and Chile, as well as high elevations of the Andes Mountains, are notably too cold for the survival of the NWS. The situation is similar for parts of the Brazilian and
The New World Screw-worm as a Pest in the Caribbean and Plans for its Eradication

Guyana highlands. An estimate of the areas of South America which are continuously NWS infested is placed at 50% with another 30% of the land area invaded each year but only to be eliminated by cold weather at the end of the warm season. This is only an estimate of the situation and data have to be collected in all of the countries in order to determine the true situation.

The twin island state of Trinidad and Tobago is also NWS infested. Given its geographical location with its almost contiguous border with South America an eradication effort at this time would best be considered in association with this area and not as a part of the Caribbean. This may well be so unless new information to the contrary becomes available.

Table 3. Estimated cost of eradicating the NWS from Hispaniola.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>ESTIMATED COST US$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterile Flies (estimated at 1,700/million for 2 years)</td>
<td>17,000,000</td>
</tr>
<tr>
<td>Chilled Fly Chambers for Fly Emergence</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Information Campaign</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Quarantine Campaign</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Administration</td>
<td>1,500,000</td>
</tr>
<tr>
<td>Dispersal Centre Operation</td>
<td>9,050,000</td>
</tr>
<tr>
<td>Miscellaneous Costs</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Field Operations</td>
<td>3,000,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>35,550,000</strong></td>
</tr>
</tbody>
</table>

JAMAICA

Jamaica lies in the Caribbean Sea 145 km south of the southernmost extremity of Cuba. The greatest length of the island is 235 km and its greatest width 82 km. The topography consists mainly of coastal plains around the island separated by a central mountain range running from the east with hills and a limestone plateau occupying the central and western areas of the interior. The land area is estimated at 11,422 km². The island has a tropical climate which is modified by the influence of the sea, the trade winds, and to a lesser extent, by land and sea breezes. There are four seasons distinguishable mainly by the differences in rainfall but conditions are not uniform over the island and vary considerably according to altitude and location.

Usually, the major rainy season starts in August and reaches a peak in May. However, periods of heavy rainfall and drought may occur at any time during the year. The lowest temperature occurs in January or February; the peak temperature usually occurs in July or August. In coastal areas, the average daily temperature ranges from about 23-28°C. However, the temperature often rises to about 30°C during the afternoon and may fall as low as 18°C in the early mornings during the cool season.

Screw-worm infestation is widespread in Jamaica and regardless of seasonal variations, altitude or ecological conditions. All types of livestock operations are affected irrespective of size and management practice. Vo (2000) estimated that the annual benefits from eradication would be between US$5.5 million and US$7.7 million. Benefits were defined as losses avoided due to: 1) mortality, 2) additional expenses for
labour associated with surveillance, prevention and treatment of infested wounds, and 3) loss in productivity of infested animals. Assuming an eradication cost of US$9.0 million, she calculated net savings after 3 years as ranging from US$4.2 million to US$13.5 million. She further estimated net benefits to be between US$25 million and US$43 million after 10 years.

Active infestations are likely to occur in any season but appear to be related to the wetter periods. However, this pattern is modified by traditional production schemes for calving, branding etc. In most instances, wounds are treated by the owner and not reported to veterinarians. Snow et al. (1976) reported that peak occurrence was in October during the major rainy season, and that there was a smaller peak in February, several months before the minor rainy season. They reported 210 cases in their paper as cattle (151), swine (20), sheep (11), goats (23) and horses (5).

Cattle were by far the principal economic host, followed by swine and goats. They reported dogs were more likely to be the single most important host of the screw-worm in Jamaica. Private veterinarians have reported to the senior author that 15-30% of clinically treated dogs were for screw-worm infestation. Dogs are most heavily infested during the mating seasons when they stray from home for days at a time and become wounded while fighting.

Unlike cattle, dogs are rarely treated until after infestation. Rawlins and Sang (1984) reported pigs as the most important host in Jamaica and that screw-worms occurred in all parishes. Table 1 shows data taken from this paper where they reported that infestation was the most prevalent in the umbilicus of neonates, bites and barbed wire cuts. Tick bites, castration wounds and branding scars were of lesser significance.

The occurrence of screw-worm infestation in Jamaica is such that potentially all wounds occurring at any time of the year will become infested. We estimate that 80% or more of all untreated wounds would become infested. Most producers have become so accustomed to living with the screw-worm that they take prophylactic actions without considering the cost involved.

The livestock operations range from large-scale to medium-size commercial smaller backyard and “down-the-road” type operations. Cattle production comprises the largest and most important component of livestock industry in Jamaica with approximately 350,000 heads, beef (67%), dairy (15%) and dual purpose and draft animals the other 18%. Currently, Jamaica is not self-sufficient in beef production but hopes to attain this goal in the next 10 years. The other livestocks of importance include goats (440,000), pigs (210,000), equines (33,000) and sheep (4,000). Most of these animals, particularly goats, are found in small-type operations of fewer than 5 animals. However, all operations, regardless of size, have some methods of controlling screw-worm infestation.

No wild animals capable of supporting infestations such as the white-tailed deer, rabbits, opossum or peccaries, are present in Jamaica. The only likely candidates are a few wild pigs in the eastern region of the island and the mongoose, an animal introduced in the last century to destroy rats and snakes in the sugar plantations. It has not been determined if the mongoose serves as a reservoir host for the NWS.

Reports of human myiasis have been made by both public and hospital officials who considered this a minor problem. However, anecdotal information suggests that NWS myiasis in humans is a significant problem on the island. It should be noted that a major problem in terms of determining the true prevalence rate is that of non- or under-reporting of cases. The cases reported are for the most part observed in children, the senile, the mentally retarded and individuals not receiving adequate medical attention or
those experiencing substandard levels of personal hygiene. Usually, infestations are found in the legs, toes, facial sores and nasal cavities.

**THE ERADICATION PROGRAMME**

The plan is to eradicate the NWS from Jamaica by the use of the sterile insect technique (SIT) which involves the sequential aerial dispersion of adequate numbers of radiation-sterilised NWS over the entire island. An estimated twenty million pupae per week will be obtained from the Mexican-US Screw-worm Commission in Mexico. These pupae will be flown weekly to emergence facilities in Jamaica. Once emerged, pupae will be subjected to aerial release 4 days of each week. An estimated 15 million sterile flies are expected to emerge from the 20 million pupae each week, thereby making for a 1,200 sterile flies / km² aerial release over the entire country.

It is estimated that this eradication programme will require three years for completion. This includes six months for the programme organisation, two years of sterile fly releases and another six months for free-status verification. The cost of the programme will be approximately US$9 million. Most of these funds will be used for the purchasing of flies and the aerial release component of the programme. The necessary funds for implementation have been secured through budgetary allocations by the Jamaican government and with financial assistance from the International Atomic Energy Agency (IAEA). Additional support will be given through a “cess” on the slaughter of cattle agreed to by the local livestock association. Technical and “in kind” assistance will also be provided by the USDA/ARS and the US-Mexican Screw-worm Eradication Commission (Table 4).

<table>
<thead>
<tr>
<th>ITEM</th>
<th>ESTIMATED COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterile Flies (estimated at 1,700/million for 2 years)</td>
<td>3,536,000</td>
</tr>
<tr>
<td>Chilled Fly Chambers for Fly Emergence</td>
<td>500,000</td>
</tr>
<tr>
<td>Information Campaign</td>
<td>800,000</td>
</tr>
<tr>
<td>Quarantine Campaign</td>
<td>50,000</td>
</tr>
<tr>
<td>Administration</td>
<td>1,214,000</td>
</tr>
<tr>
<td>Dispersal Centre Operation</td>
<td>1,500,000</td>
</tr>
<tr>
<td>Miscellaneous Costs</td>
<td>300,000</td>
</tr>
<tr>
<td>Field Operations</td>
<td>1,100,000</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>US$ 9,000,000</strong></td>
</tr>
</tbody>
</table>

To facilitate the economic and effective use of SIT and to ensure an early positive impact, implementation will be supported by ground-based activities aimed at reducing the local wild fly population. Intensive animal inspection measures and wound treatment regimes will be initiated in collaboration with local livestock owners. These activities will involve the regular inspection of all domestic animals throughout the island and will include prophylactic and curative treatment with selected insecticides. Larvae found in wounds will be collected, recorded, preserved and identified. The data
obtained will be used as the basis for estimating the density and distribution of the screw-worm and for monitoring the progress made towards final eradication.

Finally, to prevent the spread of infestation, all livestock movement will be effectively controlled through the strengthening of quarantine and other existing regulatory measures. Similarly, all animals will be inspected and treated prior to their leaving the country and with strict import entry for all animals regarding screw-worm-free status. Animals with infested wounds or with abrasions susceptible to infestation will be quarantined and treated. At some point in the future, we believe that following a successful Jamaican programme, similar eradication programmes will be planned and be implemented for the other Caribbean islands.

In summary, the available information suggests that NWS myiasis is well recognised and acknowledged to be economically devastating to the livestock sub-sector of the Caribbean. Despite this fact, in most of these countries, competing national priorities for scarce budgetary allocations may suggest that such eradication programmes might not be seen as being expedient at this time. However, based on known experience, the immediate and long-term returns from a NWS-free status will more than off-set the cost of any eradication programme. More importantly, the eradication of the NWS has repeatedly been shown to contribute greatly to the alleviation of rural poverty and the promotion of an orderly development of integrated crop and livestock production systems in those countries which have undertaken such a programme.

A successful Jamaican eradication programme would not only serve as a model for future eradication efforts in the other countries of the Caribbean but should also serve as an important barrier against re-infestation of already free areas of both the Caribbean and mainland America.

REFERENCES


Insurance Against an Old World Screw-worm Fly Invasion of Australia

Neil Tweddle1 and Rod J. Mahon2

1 Emergency Disease Strategies Section, National Office of Animal and Plant Health, GPO Box 858, Canberra, ACT 2601, Australia
2 CSIRO Entomology, GPO Box 1700, Canberra, ACT 2601, Australia; CSIRO, Institute Haiwan, P.O. Box 520, 86009, Kluang, Johor, Malaysia

Australia is fortunate that neither the New World screw-worm fly Cochliomyia hominivorax (Coquerel) (NWSWF) nor the Old World screw-worm fly, Chrysomya bezziana, Villeneuve (OWSWF), have become established within our country, although much of the northern areas are environmentally suitable (Suthurst et al. 1989). The OWSWF is a substantial threat as it is prevalent in the neighbouring countries of Papua New Guinea and Indonesia. Perhaps more importantly, it is also present in many of our trading partners in Southeast Asia. The export of live cattle from northern Australian ports to Southeast Asian nations has become an important and rapidly expanding trade. The fly is also present near ports in the Middle East which receive considerable numbers of live sheep exported from various Australian ports. In both situations, there is the ever-present opportunity for the screw-worm fly (SWF) to return to Australia as larvae, pupae or adults on stock carrying vessels. While this means of transport probably represents the most likely route for the pest to gain access to Australia, accidental transport on aircraft and active myiases on humans or companion animals remain possibilities.

The introduction of the NWSWF into Australia is considered unlikely, but not impossible. Indeed, in 1992, an Australian tourist returning from South America carried live NWSWF larvae into Australia in a neck wound. Fortunately, the diagnosis was made early and the wound was treated, preventing any larvae evacuating. This was in southern Australia in May, where climatic conditions are unlikely to favour survival at that time of the year, but it demonstrates the potential for inadvertent introduction.

Models of the impact of the OWSWF indicate that the cost of an invasion would be high. It has been estimated by Anaman et al. (1993), that the annual cost in an average climate year to beef cattle, sheep and dairy producers of an endemic establishment would be A$281 million. These costs would be trivial in comparison with the societal cost (McKelvie et al. 1993). Extensive cattle grazing is the dominant industry throughout much of the northern pastoral areas of Australia. It is likely, based on USA experience, that extensive cattle production, as practised in northern Australia, would not be viable if SWF became established.

The extensive grazing industries could theoretically maintain herd numbers in the presence of the OWSWF; however, the labour costs of doing so would be crippling. In areas where the fly is endemic, e.g., Malaysia, beef cattle must be inspected as frequently as every three days in order to deal with new myiasis cases. This is in stark contrast to practices in the Australian extensive pastoral zone, where cattle are inspected rarely, perhaps as infrequently as once or twice each year. In the presence of the OWSWF, this would result in high mortality among adult cattle and extensive mortality among newborn calves, causing serious reduction in recruitment. A characteristic site of

Area-Wide Control of Fruit Flies and Other Insect Pests, ed. K.H. Tan. Penerbit Universiti Sains Malaysia, Penang, 2000. 95
OWSWF infestations is the navel of new-born calves which if untreated, quickly cause the death of the calf. The failure of the livestock industries would in turn impact severely on the small to medium towns servicing the industries and, as there are few or no viable alternative business opportunities, many could die.

Australia's native fauna is naive to this pest and it is inevitable that some impact on the fauna would occur if an incursion occurred, although it is impossible to predict the extent. It is of concern to note that the NWSWF finds the pouch of the American opossum an attractive oviposition site, and if the OWSWF was similarly attracted, the impact on our diverse marsupial fauna could be severe. Human cases of myiasis also occur, although the incidence is poorly documented (Searson et al. 1992). An exception is the records from Iraq where numerous human myiasis cases have occurred following an invasion of the OWSWF into that country in 1996.

The Department of Primary Industries and Energy (DPIE) Australia has developed contingency plans to respond to a number of exotic diseases, in collaboration with state governments and the livestock industries. The OWSWF is considered one of the most serious among them. The Australian Veterinary Emergency Plan (AUSVETPLAN 1996) contains a strategy for the control and eradication of the screw-worm fly if ever it gains a foothold on our continent. The policy is to eradicate the pest in the shortest possible period, while limiting economic impact using a combination of strategies including:

- The **sterile insect release method (SIRM)** to control and eradicate the fly.
- **Quarantine and movement controls** in declared areas to prevent the movement of infested animals.
- **Decontamination and disinfestation** of larvae/pupae-contaminated areas and things.
- **Tracing and surveillance** to determine the source and extent of the infestation, and to provide proof of freedom from the disease.
- **Treatment** of individual animals and groups, to prevent or cure infestation especially before movement.
- **Zoning** to define infected and disease-free areas.
- A **public awareness campaign** to encourage rapid reporting of suspected infestations, and to facilitate cooperation from industry and the community.

A fundamental plank in the eradication plan is the implementation of SIRM. Models prepared for DPIE using the best available data (unfortunately largely from NWSWF sources) indicate that an 8:1 benefit-cost ratio would be achieved through undertaking an eradication programme (Anaman et al. 1993). The modelling indicates that large areas of tropical and sub-tropical Australia are suitable for year round survival of the SWF, with further southern extensions in summer that would recede after frosts (Anaman et al. 1993). Incursions in southern areas would not persist over winter, but incursions or spot outbreaks in the south from northern endemic areas could be active over spring, summer and autumn.

The OWSWF has great dispersal ability (Spradbery et al. 1995) and it is anticipated that by the time a SIRM programme can be mounted, the fly will have colonised 500,000 km². Under this scenario, eradication would take nearly two years. It is envisaged that a facility capable of producing 200 or 250 million flies per week would be required to achieve eradication. Such a facility would be extremely expensive to construct and there would be intense pressure to complete it as quickly as possible to prevent further spread of the fly and to minimise economic losses. Under such
circumstances, it would be advantageous to know exactly what should be constructed, and perhaps even have blueprints for tried and tested systems on the shelf ready to implement. This is the rationale for a experimental mass rearing facility, the Institut Haiwan Screw-worm Fly Laboratory in Kluang, Malaysia (Mahon and Ahmad, in this volume), where we hope to apply production engineering methods to the rearing of the OWSWF. In addition, a demonstration that mass reared and sterilised OWSWF were fit under field conditions is considered important in order to confirm and provide confidence in the efficacy of a SIRM programme before embarking on such a large and expensive exercise. This is a collaborative project between DPIE and the Department of Veterinary Services, Malaysia (DVS). DVS has provided the land and a number of staff, while DPIE has provided the capital for the construction of the facility, and Australian producer research and development funding bodies (the Meat Research Corporation, the Australian Wool Research and Promotion Organisation and the Dairy Research and Development Corporation) are providing the funds for the research and development (R & D) programme.

At the completion of this project, a design brief will be produced that would facilitate the construction of a 250 million sterile flies per week facility within Australia if ever it were required. Models indicate that there is merit in construction of the facility and mothballing it until required, though funding of this option may prove difficult. Nevertheless that option will be presented to producers to consider. Insurance policies against insects are expensive!

A multi-species sterile insect production facility was another attractive option evaluated by Anaman et al. (1993). The multi-insect facility concept would see the plant being used for production of sterile insects for control or eradication of endemic pests (e.g., the Queensland fruit fly, the Australian sheep blowfly) until an incursion by an exotic insect pest. The already-operational plant would then be fairly quickly diverted (in full or part) to the production of sterile SWF or other exotic insect horticultural pests. Since production could start earlier in an outbreak, a smaller capacity would be required, as the pest distribution would still be restricted. The estimated benefit-cost ratios for a range of options, based on producer losses only (Anaman et al. 1993) or economic surplus changes for producers and consumers (McKelvie et al. 1993), are very favourable. A full feasibility study of a multi-insect facility is yet to be undertaken.

SIRM could be ineffective if Chrysomya bezziana populations from different geographic locations proved to be a complex of sibling species (Strong and Mahon 1991). To explore this potential limitation, a study was initiated to determine the extent of inter-population variability within what we know as C. bezziana. Collections were made from as many localities as possible throughout the species’ geographic range, and included South Africa and Zimbabwe in southern Africa, Oman in the Middle East, Malaysia, Indonesia and Papua New Guinea in Southeast Asia. A range of techniques previously shown to indicate the presence of sibling species and/or variability within insect populations was applied to the collection. The allozyme study (Strong and Mahon 1991) indicated that intra-population variation was remarkably limited, despite the extensive geographical range of the species. From this result, Strong and Mahon (1991) postulated that as gene flow from the extremes of the range is highly unlikely, it is likely that the species has “recently” expanded its range. Perhaps the range expansion occurred with human aid. Hybridisation tests (Spradbery, unpublished) indicated that adults from different populations would mate, and viable and fertile offspring could be produced. Cytogenetic studies (Bedo et al. 1994) and biochemical profiles of the cuticular hydrocarbons also indicate that while minor variability occurs, there is no indication that Chrysomya bezziana consists of a complex of sibling species. Thus,
Insurance Against an Old World Screw-worn Fly Invasion of Australia

while it would be ideal if the colony used to breed sterile flies for SIRM is from the same location as the source of an incursion into Australia, probably any colony would be effective.

There are other components of the AUSVETPLAN designed to both minimise losses and supplement a SIRM eradication programme. An early warning system has been established as part of the North Australian Quarantine Strategy (NAQS), which is based on enhanced quarantine surveillance, education, and a regular trapping programme using “Swormlure”, an attractant developed for NWSWF. A review of the NAQS SWF monitoring programme was undertaken in 1991 (Nunn et al. 1991). As a result of the report, the trapping sites and monitoring programme were modified to improve the chances of early detection. Particular care is taken to prevent the entry of the SWF with returning livestock vessels. Educational programmes have also been implemented to make livestock owners and residents of northern Australia and the Torres Strait more aware of the SWF. Kits have been provided and promoted to encourage the submission of larvae from strikes on animals.

Despite the surveillance, depending on the location of an incursion of the OWSWF, it might be several months before an incursion is detected. Unless a SIRM facility was in existence, a further delay of between one to two years would occur before a SIRM programme could be implemented.

In the interim, restrictions on stock movements would be applied within the infested area in order to limit the spread of the pest though transfer of infected stock. A restricted area will be declared enclosing the infested area and movement of animals within or out of the restricted area will be allowed, subject to inspection, treatment and permit. Treatment with avermectin, a systemic drug, will be mandatory to all animals prior to movement, with movement permitted 7–14 days after treatment. Animals showing clinical evidence of SWF infestation will be sampled and treated with approved insecticidal smears/pressure packs at the time of the systemic insecticide treatment and inspected again before moving. A larger Control Area will be declared around the Restricted Area. Movement of animals within, or out of, the control area will be by inspection and permit, without treatment, unless required.

As natural dispersal of the adult fly and dispersal via myiases on native fauna will be inevitable, barriers around known infested areas will be forced to continually retreat until the SIRM programme can be implemented. Surveillance for the presence of the pest in as yet uninfested areas will be important, in order to identify new outbreaks and erect new barriers to limit stock movements.

Ivermectin and avermectin are effective systemic parasiticides against larval stages of the OWSWF (Spradbery et al. 1991) and would be used for the treatment of infected animals. Topical treatment of struck wounds with smears or pressure pack insecticides, followed by a systemic insecticide for at-risk animals, is recommended. Ivermectin prophylaxis is preferable for animals wounded in the course of normal husbandry procedures. Wounds are still attractive to the SWF after ivermectin treatment; however, larvae hatching from egg masses laid by female flies will be killed.

Treatment of all myiases located would help reduce the population of the OWSWF, and thereby perhaps, the incidence of new myiases, and should reduce the rate of dispersal. Native and feral animals are a problem, since they cannot be effectively treated. The new chemical, Moxidectin (Cyanamid), has recently been released onto the Australian market. Moxidectin has similarities to the ivermectin group but may be less damaging to the environment. This drug has not been assessed for efficacy against larval OWSWF. An assessment of the efficacy of Moxidectin and new formulations of ivermectin against the OWSWF is proposed.
Public awareness and early reporting of suspect myiasis are given major emphasis both prior to and in response to an outbreak. A video, Recognising Exotic Livestock Disease No. 7: Screw-worm Fly, has been produced as part of a series to alert veterinarians and other health professionals, to the threat of SWF. It instructs on the epidemiology and clinical signs of the disease. The SWF is also included in general awareness material published from time to time, as well as in feature articles, radio interviews and other materials. Specimen collection kits are supplied to producers (and health centres) in northern Australia to encourage submission of larvae from myiasis strikes when seen. A diagnostic manual has been prepared (Spradbery 1991) and training given in identifying and differentiating the SWF from other species. The NAQS education programme in northern Australia also has a significant emphasis on the SWF.

In conclusion, the approach Australia has taken to provide insurance against invasion by the SWF, has been to undertake preventative and early recognition measures, to identify and quantify the economic and public health threats, and finally, to develop the science for control and eradication that should enable an effective eradication response to be implemented.

REFERENCES


Incidence of Old World Screw-worm Fly, *Chrysomya bezziana* in Iraq

Ayad A. Al-Taweel¹, Mohammed A.J. Al-Izzi¹ and Fadhil A. Jassim²

1 Entomology Department, IAEC, P.O. Box 765, Baghdad, Iraq
2 Faculty of Veterinary Services, Ministry of Agriculture, Baghdad, Iraq

INTRODUCTION

The Old World screw-worm fly (OWSWF), *Chrysomya bezziana* Villenuve, is a member of the insect family Calliphoridae and is an obligate parasite of warm-blooded animals in the tropics and sub-tropics (Norris and Murray 1964). Flies lay their eggs on the edge of wounds or body orifices; the resulting larvae invade the host tissues and produce lesions and infertility if the genitals become infested (Humphrey et al. 1980). Recorded hosts include cattle (*Bos indicus*), sheep (*Ovis aries*), goats (*Caprus hircus*), dogs (*Canis familiaris*), cats (*Felis domesticus*) and man (*Homo sapiens*) (Patton 1920, 1922, Stoddar and Peck 1962, Norris and Murray 1964). This investigation describes the incidence of myiasis caused by *C. bezziana* in Iraq from September 1996 to March 1998.

MATERIALS AND METHODS

On 9 September 1996, Iraqi veterinary officers noticed an unusual myiasis case presentation along the river bank of the Tigris river within the Baghdad governorate. The infestation caused a hole inside the infested tissues which resulted in rotten areas, accompanied by filtration of liquid serum and distortion of the tissue with larvae of different stages. The veterinary officers were advised to collect a sample of at least ten larvae and treat wounds with available insecticidal preparation. These larvae were sent to a main governmental veterinarian clinic in Baghdad for identification with the collaboration of the Natural History Museum/Baghdad University following Zumpt (1965) and Spradbery (1991). This method has been followed in all governorates where such natural infestation is detected. On the other hand, egg masses and larvae were reared in the entomology laboratory/IAEC on a meat diet consisting of:

- Minced beef 58%
- Whole blood 15%
- Distilled water 27%

Blood was obtained from the jugular venepuncture of cattle or from slaughterhouses and EDTA (1%) was added to prevent clotting. These egg masses and larvae were put on the meat based diet in small containers and maintained at a temperature of 37°C in an incubator. The diet was changed regularly. At about six days, the larvae migrated from the food, or were transferred to trays containing corncob grits for pupation. The pupae were maintained at room temperature for about 6-8 days; then
the young flies were collected for identification following the Spradbery manual (1991) or were kept for rearing.

RESULTS AND DISCUSSION

During the 19 months of the census, 58,063 cases of myiasis were recorded (Table 1) with 13.9% occurring during 1996 from the time the first case was reported on 9 September 1996, 80.7% occurring during 1997 and 5.4% occurring during the first three months of 1998. This was in spite of the use of available insecticides such as ectopor, diazinon, nagaasunt and coumaphos. Furthermore, 22 human cases were also recorded with 54.5%, 22.7%, 9.1%, 9.1% and 4.5% in the Diyala, Babil, Karbala, Basrah and Wassit governorates respectively.

Table 1. Number of Old World screw-worm fly myiasis in Iraq distributed according to the governorates.

<table>
<thead>
<tr>
<th>Governorate*</th>
<th>Date of first record</th>
<th>Myiasis cases in animals**</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Up to 31/12/96</td>
<td>1/1/97</td>
</tr>
<tr>
<td>Baghdad (C)</td>
<td>09/09/96</td>
<td>1802</td>
<td>9327</td>
</tr>
<tr>
<td>Diyala (E)</td>
<td>12/09/96</td>
<td>1604</td>
<td>899</td>
</tr>
<tr>
<td>Karbala (W)</td>
<td>17/09/96</td>
<td>2935</td>
<td>10422</td>
</tr>
<tr>
<td>Wassit (S)</td>
<td>23/09/96</td>
<td>119</td>
<td>1089</td>
</tr>
<tr>
<td>Babil (W)</td>
<td>25/09/96</td>
<td>823</td>
<td>17827</td>
</tr>
<tr>
<td>Qadesiya (S.W.)</td>
<td>29/09/96</td>
<td>53</td>
<td>2129</td>
</tr>
<tr>
<td>Anbar (N)</td>
<td>14/10/96</td>
<td>11</td>
<td>1863</td>
</tr>
<tr>
<td>Najaf (W)</td>
<td>27/10/96</td>
<td>693</td>
<td>2673</td>
</tr>
<tr>
<td>Muthanna (S)</td>
<td>02/01/97</td>
<td>-</td>
<td>463</td>
</tr>
<tr>
<td>Tikrit (N)</td>
<td>01/10/97</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Thi-Qar (S)</td>
<td>11/11/97</td>
<td>-</td>
<td>148</td>
</tr>
<tr>
<td>Missan (S)</td>
<td>20/11/97</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Basrah (S)</td>
<td>14/12/97</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>8040</td>
<td>46874</td>
</tr>
</tbody>
</table>

* C = Centre; E = East (relative to C); W = West; S = South and N = North
** Weekly data collected at government veterinarian clinics

The monthly incidence of myiasis in relation to prevailing meteorological conditions suggested that myiasis was more common during the cooler seasons of the year and rare during the hot, dry summer (Table 2). Furthermore, this table also shows that 4.6% of cases occurred during autumn 1996, 21.1% in winter 1996-1997, 2.2% in
spring 1997, 1.5% in summer 1997 and 25.7% and 44.7% in autumn 1997 and winter 1997-1998 respectively.

Table 2. Number of Old World screw-worm fly myiasis cases recorded in Iraq monthly.

<table>
<thead>
<tr>
<th>Month</th>
<th>Total Myiasis Cases</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Average</td>
</tr>
<tr>
<td>September 1996</td>
<td>266</td>
<td>30</td>
</tr>
<tr>
<td>October 1996</td>
<td>433</td>
<td>25</td>
</tr>
<tr>
<td>November 1996</td>
<td>1959</td>
<td>16</td>
</tr>
<tr>
<td>December 1996</td>
<td>5386</td>
<td>11</td>
</tr>
<tr>
<td>January 1997</td>
<td>4361</td>
<td>10</td>
</tr>
<tr>
<td>February 1997</td>
<td>2418</td>
<td>11.5</td>
</tr>
<tr>
<td>March 1997</td>
<td>999</td>
<td>16</td>
</tr>
<tr>
<td>April 1997</td>
<td>180</td>
<td>22</td>
</tr>
<tr>
<td>May 1997</td>
<td>113</td>
<td>26</td>
</tr>
<tr>
<td>June 1997</td>
<td>179</td>
<td>32</td>
</tr>
<tr>
<td>July 1997</td>
<td>254</td>
<td>35</td>
</tr>
<tr>
<td>August 1997</td>
<td>431</td>
<td>34</td>
</tr>
<tr>
<td>September 1997</td>
<td>766</td>
<td>30</td>
</tr>
<tr>
<td>October 1997</td>
<td>3123</td>
<td>25</td>
</tr>
<tr>
<td>November 1997</td>
<td>11042</td>
<td>16</td>
</tr>
<tr>
<td>December 1997</td>
<td>23004</td>
<td>12.5</td>
</tr>
<tr>
<td>January 1998</td>
<td>2462</td>
<td>9</td>
</tr>
<tr>
<td>February 1998</td>
<td>353</td>
<td>-</td>
</tr>
<tr>
<td>March 1998</td>
<td>334</td>
<td>-</td>
</tr>
</tbody>
</table>

Finally, it can be seen from Table 3 that the cases of OWSWF myiasis in the four governorates of the central region of Iraq fluctuated throughout the nineteen months of the survey in spite of the use of insecticides. For example, in Baghdad, the lowest number recorded by governmental veterinarian clinics was during April 1997 when the minimum and maximum temperatures were 7°C and 33°C respectively, while the highest number recorded was during December 1997 when the minimum and maximum temperatures were 9°C and 24°C respectively.
Table 3. Number of Old World screw-worm fly myiasis in the central region of Iraq.

<table>
<thead>
<tr>
<th>Month</th>
<th>Baghdad</th>
<th>Diyala</th>
<th>Karbala</th>
<th>Babil</th>
</tr>
</thead>
<tbody>
<tr>
<td>September 1996</td>
<td>153</td>
<td>71</td>
<td>36</td>
<td>2</td>
</tr>
<tr>
<td>October 1996</td>
<td>82</td>
<td>165</td>
<td>107</td>
<td>75</td>
</tr>
<tr>
<td>November 1996</td>
<td>520</td>
<td>431</td>
<td>739</td>
<td>178</td>
</tr>
<tr>
<td>December 1996</td>
<td>1047</td>
<td>937</td>
<td>2053</td>
<td>568</td>
</tr>
<tr>
<td>January 1997</td>
<td>752</td>
<td>102</td>
<td>2075</td>
<td>124</td>
</tr>
<tr>
<td>February 1997</td>
<td>229</td>
<td>139</td>
<td>404</td>
<td>137</td>
</tr>
<tr>
<td>March 1997</td>
<td>108</td>
<td>0</td>
<td>324</td>
<td>66</td>
</tr>
<tr>
<td>April 1997</td>
<td>6</td>
<td>0</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>May 1997</td>
<td>21</td>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>June 1997</td>
<td>29</td>
<td>1</td>
<td>24</td>
<td>2</td>
</tr>
<tr>
<td>July 1997</td>
<td>88</td>
<td>3</td>
<td>44</td>
<td>0</td>
</tr>
<tr>
<td>August 1997</td>
<td>109</td>
<td>0</td>
<td>170</td>
<td>5</td>
</tr>
<tr>
<td>September 1997</td>
<td>119</td>
<td>0</td>
<td>108</td>
<td>289</td>
</tr>
<tr>
<td>October 1997</td>
<td>588</td>
<td>35</td>
<td>1014</td>
<td>988</td>
</tr>
<tr>
<td>November 1997</td>
<td>972</td>
<td>508</td>
<td>1306</td>
<td>6172</td>
</tr>
<tr>
<td>December 1997</td>
<td>6306</td>
<td>107</td>
<td>4951</td>
<td>8077</td>
</tr>
<tr>
<td>January 1998</td>
<td>622</td>
<td>0</td>
<td>254</td>
<td>312</td>
</tr>
<tr>
<td>February 1998</td>
<td>85</td>
<td>0</td>
<td>0</td>
<td>124</td>
</tr>
<tr>
<td>March 1998</td>
<td>30</td>
<td>204</td>
<td>0</td>
<td>25</td>
</tr>
</tbody>
</table>

It is concluded from these data that fast action is needed to control this pest because using insecticides alone is not enough. Therefore, we believe that the sterile insect technique (SIT) is the only successful method for controlling it.

REFERENCES

Cuticular Hydrocarbons of *Glossina austeni* and *Glossina pallidipes*: Similarities Between Populations and Activity as Sex Pheromones

**D.A. Carlson**, **B.D. Sutton** and **U.R. Bernier**

1 USDA, Agricultural Research Service, Center for Medical Agricultural and Veterinary Entomology, P.O. Box 14565, Gainesville, FL 32604, USA
2 Department of Agriculture and Consumer Affairs, State of Florida, Gainesville, FL 32611, USA

**INTRODUCTION**

Tsetse flies are a hazard to the health of humans and domestic animals because they spread trypanosomiasis, also known as nagana. *Glossina austeni* Newstead and *Glossina pallidipes* Austen are important vectors of this disease in East Africa. Sex pheromones were shown to be present in the surface or cuticular hydrocarbon waterproofing waxes of female of several species of the tsetse fly (Huyton et al. 1980). The pheromones identified in *Glossina morsitans morsitans* Westwood (Carlson et al. 1978) and *G. pallidipes* (Carlson et al. 1984, McDowell et al. 1985) have been shown to consist of species-specific, long-chain, high molecular weight hydrocarbons with several methyl branches, present with at least 20 other hydrocarbon compounds in the surface waxes (Nelson and Carlson 1986, Nelson et al. 1988, Sutton and Carlson 1997). The assignment of KI (Kovac Index) narrows the range of possible methyl-branch configurations in cases of ambiguous or insufficient EI (electron impact) spectra (Carlson et al. 1998). We used gas chromatography/mass spectrometry to demonstrate that different populations of tsetse flies (Carlson et al. 1993) are closely related by investigating these patterns of surface hydrocarbons.

**G. austeni**

**Chemical separation**

We attempted to isolate and identify sex pheromones found in female flies, by open-column chromatography. Bioactivity was found only in the surface hydrocarbons extracted from females. Normal-phase column chromatography on silica gel and argentation chromatography indicated that the hydrocarbon fraction contained both alkanes and alkenes (unsaturated hydrocarbons with one double bond) (Carlson and Langley 1986). Gas chromatography (GC) of the cuticular hydrocarbons of individual specimens and pooled samples was supported by GC-mass spectrometry (GC-MS) to identify the hydrocarbons found in each GC peak. The major alkanes from females were consistent with previously published data on this species, which demonstrated that they possess two homologous isomers, 13,17-dimethyltritriacontane and 13,17-dimethylpentatriacontane. The two major alkene peaks in females also contained previously unknown compounds, namely 13,17-dimethyltritriacont-1-ene, and 13,17-dimethylpentatriacont-1-ene, structures determined by GC-MS after derivation with deuterium or dimethyldisulfide (Carlson et al. 1989) (Figure 1).
Cuticular Hydrocarbons of *Glossina austeni* and *Glossina pallidipes*

Figure 1. Gas Chromatographic analysis of alkenes from mated *G. austeni* females before and after formation of derivatives.

Bioassays

Contact sex stimulant activity was studied in bioassays in Austria and Tanga, Tanzania, using tests similar to those used in previous studies with other species (Carlson et al. 1978, 1984). Test showed that the alkanes were not active, but that the unsaturated fraction was active. Dose-response data showed ED₅₀ at ca. 5 μg per decoy, using solvent-washed female flies of different species as decoys. This is the first example in a tsetse fly that sexual activity was initiated in males by alkenes, including most of the mounting behaviours released by contact with conspecific females. So far as is known, these alkenes were structurally the same among all specimens examined. Whether one or both of these compounds are responsible for this behaviour is not known.

Analysis of other specimens

The alkane fractions of conspecific females from seven locations were analysed to determine differences and similarities. They appeared to cluster into three groups: 1) Bristol laboratory, ILRAD/Kenya/Bristol, Maisons-Alfort/Bristol, Vienna, Tanga laboratory, 2) Mozambique wild, Natal-Zululand-SA wild, and 3) Kenya wild (Figure 2). The significance of these differences is not known, since the alkanes are not known to possess biological activity.
Figure 2. Gas Chromatographic analysis of alkanes from *G. austeni* females from different locations.

The alkenes of these specimens are under investigation, but appear universally the same by GC. There appear to be only two compounds present in the active fraction from unmated females. The male-produced compound is structurally similar, but its biological activity is unknown.

*G. pallidipes*

**Chemical separation**

The sex stimulant pheromone of this species consists of female-produced 13,21-dimethylpentatriacontane, with smaller amounts of chemical homologues. The alkanes of conspecific females from several locations were analysed to determine differences and similarities with published work on the sex pheromone of the species. The surface lipids were obtained by extracting individual specimens and/or pooled specimens in hexane, then concentrating the extracts before normal phase chromatography and argentation chromatography. The alkane fractions were analysed by GC (Figure 3) and GC-MS.
Bioassays

No bioassays have been conducted recently.

Analysis of other specimens

New specimens and several older samples were re-examined recently. All females analysed contained a major component consisting of 13,21-dimethyl C35, a minor 11,21-dimethyl C35 isomer and much smaller amounts of homologous 13,21-dimethyl C36 and 37 carbon alkanes. These recent results, and data published previously (Table 1), were compared. The quantities of the major C35 pheromone found were similar, at 7 to 13 µg per female, although the old laboratory females contained more. The results appeared to cluster the females into two groups: 1) Amsterdam, ICIPE/Kenya, Kenya, Tanzania wild, Uganda/Bristol, Arba Minch/Ethiopia, 2) Zimbabwe wild (not shown). The biological significance of these differences is not known.
Table 1. Sex pheromone components recovered from female *G. pallidipes*.

<table>
<thead>
<tr>
<th>Origin of females</th>
<th>11,21/-13,23-Me2C35** proportions found (year)</th>
<th>Quantity in µg/female (age in days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bristol</td>
<td>1/5</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>1/3 (1978)</td>
<td></td>
</tr>
<tr>
<td>Mozambique</td>
<td>Trace/l</td>
<td></td>
</tr>
<tr>
<td>Zambia</td>
<td>Trace/l</td>
<td></td>
</tr>
<tr>
<td>Zimbabwe/Amsterdam</td>
<td>1/8</td>
<td></td>
</tr>
<tr>
<td>Zimbabwe wild</td>
<td>1/6, trace/l</td>
<td>13</td>
</tr>
<tr>
<td>Kenya/Austria colony</td>
<td>1/6.6</td>
<td>11 (8 d)</td>
</tr>
<tr>
<td>Kenya/Austria colony</td>
<td>26 (60 d), 18 (120 d)</td>
<td></td>
</tr>
<tr>
<td>Kenya (McDowell, ICIPE)</td>
<td></td>
<td>81+</td>
</tr>
<tr>
<td>Arba Minch, Ethiopia</td>
<td>1/3 (1998)</td>
<td></td>
</tr>
<tr>
<td>Uganda</td>
<td>1/3 (1998)</td>
<td></td>
</tr>
</tbody>
</table>

** Most estimates from GC-MS results, 1982-1985
+ Quantity of 13,17-dimethylpentatriacontane estimated
* From Carlson et al. 1984

**DISCUSSION**

The technical information presented here may be useful in several circumstances. First, specimens of tsetse flies collected from different populations can be chemically analysed to ensure that the cuticular chemistry and the sex pheromone, at least, are correct before a new scheme using the sterile insect technique (SIT) begins. Second, knowledge of a species-specific sex pheromone may help in modern biocontrol efforts against this disease vector by ensuring that a competitive strain of fly is used in large-scale sterile male releases. For quality control, colony females can be analysed to see that they produce such a material. Third, sexual behaviour in reared males intended for mass release can be checked against a standard. Fourth, a synthetic pheromone might be used to increase the very slow rate of reproduction in laboratory-reared flies.

The activity of the racemic synthetic sex pheromone was shown conclusively in Wageningen and ICIPE *G. pallidipes* males in 1984-86 tests (Carlson et al. 1984), although the compound was less active in bioassays against Zimbabwe males (unpublished data). This compound was present in all female *G. pallidipes* examined recently, in about the same amount, which suggests that the flies are very similar.

After the success of SIT against *G. austeni* in Zanzibar, plans have been advanced to establish SIT schemes in other locations. There have been questions about the relatedness of widely-separated populations of these flies, for example: 1) Are flies from distant populations still the same species, have they become subspecies, or strains? 2) Do they have different sexual behaviours? 3) Will males from one location recognise females from another location as conspecifics? 4) Do females from different
populations possess the same sex stimulant pheromones recognised by males? 5) Do the differences found between populations by molecular techniques (RFLP [restriction fragment length polymorphism], isozymes) have meaning if the sex pheromones between the populations are the same? 6) Are the compounds detected possible kairomones for parasitoid wasps that prefer to attack tsetse flies? 7) Can some elements of quality control for colonised flies be addressed using GC?

We believe that these and other important questions may be addressed by the use of information on cuticular hydrocarbons and sex pheromones in tsetse flies.

ACKNOWLEDGEMENTS

We (DAC) thank J. Hendrichs, A. Robinson and Udo Feldmann of the International Atomic Energy Agency for the opportunity to pursue this effort in Austria at the Seibersdorf laboratory and for travel funds to attend the FAO/IAEA Conference. We thank Andrew Parker, then at TTRI, Tanga, Tanzania for his assistance. We thank M. Hosack for her technical assistance.

REFERENCES

Economic Impact of Eradicating the New World Screw-worm 
(*Cochliomyia hominivorax*) from Jamaica

*Trang T. Vo*

Policy Analysis and Development, Policy and Program Development, Animal and Plant Health Inspection Service, U.S. Department of Agriculture, Riverdale, Maryland, USA

**INTRODUCTION**

The purpose of the study is to assess the economic feasibility of eradicating the New World screw-worm (*Cochliomyia hominivorax*) (Coquerel), from Jamaica. The endemic presence of the NWS in Jamaica has caused the livestock sector to incur recurrent economic costs and losses. Eradication of the pest utilising the environmentally-benign sterile insect technique (SIT) has proved technologically feasible on other islands and other parts of the world. Based on these successful experiences, the proposed project to eradicate the NWS from Jamaica is expected to be similarly effective in eliminating the pest from Jamaica in a relatively short period of time. The elimination of the pest from the Caribbean would lessen the significant risk of re-infestation of eradicated areas and pest-free countries in the region.

**METHOD**

In order to assess the feasibility of eradicating the NWS, information is required on the economic losses resulting from the presence of the pest in the Jamaica livestock population. The benefits of eradication is then considered to be the losses that are avoided from having the programme. Benefits are then compared with programme costs in order to determine the economic worth of eradication.

The study addresses the impacts only on livestock producers in terms of an accounting of costs and losses; impacts on consumers of livestock products, human health and pets are not considered. Information on pest incidence is obtained from a survey of 114 producers of cattle, goats, pigs and sheep. Results from the survey questionnaires are then applied to the total livestock population to obtain aggregate impacts. Five major categories of costs and losses are quantified. These include increased cost of production associated with:

- insecticides and medicine
- veterinary services
- additional time to finish animals
- additional labour for surveillance, treatment and prevention of wounds
- loss in value due to animal mortality.

**RESULTS**

Because of the differences in magnitude of the findings, loss estimates due to
mortality are based on two sources: one on the survey and the other from a 1984 study conducted by Rawlins and Sang (1984). These rates, along with the average infestation rates of young and adult animals as shown from the survey, are presented in Table 1.

Table 1. Infestation and mortality rates of screw-worm-infested livestock in Jamaica.

<table>
<thead>
<tr>
<th>Type of Livestock</th>
<th>Infestation Rates (%)</th>
<th>Mortality Rates from the Survey (%)</th>
<th>Mortality Rates from Rawlins and Sang Study (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy cattle</td>
<td>9.8</td>
<td>8.8</td>
<td>1.8</td>
</tr>
<tr>
<td>Beef cattle</td>
<td>15.1</td>
<td>6.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Goats</td>
<td>18.3</td>
<td>27.5</td>
<td>1.8</td>
</tr>
<tr>
<td>Pigs</td>
<td>11.8</td>
<td>27.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Sheep</td>
<td>12.6</td>
<td>4.8</td>
<td>1.8</td>
</tr>
</tbody>
</table>

The annual value of loss due to screw-worm deaths is estimated to be between US$624,000 (utilising the Rawlins and Sang mortality rate) and US$3 million using the rates from the recent survey.

The total increase in the cost of production of the Jamaican livestock industry of living with the screw-worm is estimated to be nearly US$5 million annually (Table 2). Expenditures for labour required for surveillance and treatment of animals comprise 74 percent of the additional production costs. Costs of insecticides and medicine represent over 23 percent of the screw-worm-related costs. These farm-level control measures that have been incorporated into livestock production practices have been the necessary tradeoffs towards minimising productivity losses.

In sum, the total losses due to mortality and increases in the cost of production are estimated to be between **US$5.5 million** and **US$7.8 million** annually. Once eradication is achieved, these costs could be avoided and can therefore be thought of as the benefits of the eradication programme.

Table 2. Increase in cost of production due to screw-worm flies.

<table>
<thead>
<tr>
<th>Production Cost Increase</th>
<th>US$</th>
<th>% of total cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Chemical Costs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Cost of Insecticides</td>
<td>1,004,616</td>
<td>23.3</td>
</tr>
<tr>
<td>- Cost of Medicine</td>
<td>106,895</td>
<td></td>
</tr>
<tr>
<td>Cost of Veterinary Services</td>
<td></td>
<td>2.4</td>
</tr>
<tr>
<td>Cost of Increased Sale Time</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Total Labour Cost</td>
<td>3,584,199</td>
<td>74.0</td>
</tr>
<tr>
<td>- Surveillance and Prevention</td>
<td>3,255,988</td>
<td></td>
</tr>
<tr>
<td>- Treatment</td>
<td>328,211</td>
<td></td>
</tr>
<tr>
<td>Total increase in costs</td>
<td>4,827,986</td>
<td></td>
</tr>
</tbody>
</table>
The eradication programme of the NWS from Jamaica is projected to take three years. Eradication is expected to be achieved by the end of the second year of initiating aerial dispersion of sterile screw-worm flies. The third year efforts would be dedicated to surveillance and monitoring activities. The project is estimated to cost between **US$4.9 million** and **US$9 million**.

Benefits and programme costs of eradication are simulated over ten years. The present values of the stream of benefits and costs, discounted at a rate of 11 percent, are then compared. Comparisons of the two ranges of benefits and programme costs are provided in Tables 3 and 4. Scenario 1 assumes a programme cost of **US$4.9 million**, while scenario 2 assumes a cost of **US$9 million**.

### Table 3. Comparison of discounted benefits and costs at the end of year 3 and year 10, assuming benefits of **US$5.5 million**.

<table>
<thead>
<tr>
<th>Discounted Value of</th>
<th>After Year 3</th>
<th>After Year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1 (US$ million)</td>
<td>Scenario 2 (US$ million)</td>
</tr>
<tr>
<td>Benefits</td>
<td>12.9</td>
<td>12.9</td>
</tr>
<tr>
<td>Programme Costs</td>
<td>4.5</td>
<td>8.2</td>
</tr>
<tr>
<td>Net Savings</td>
<td>8.4</td>
<td>4.7</td>
</tr>
<tr>
<td>Benefit-Cost Ratio</td>
<td>2.9:1</td>
<td>1.6:1</td>
</tr>
</tbody>
</table>

### Table 4. Comparison of discounted benefits and costs at the end of year 3 and year 10, assuming benefits of **US$7.8 million**.

<table>
<thead>
<tr>
<th>Discounted Value of</th>
<th>After Year 3</th>
<th>After Year 10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1 (US$ million)</td>
<td>Scenario 2 (US$ million)</td>
</tr>
<tr>
<td>Benefits</td>
<td>18.3</td>
<td>18.3</td>
</tr>
<tr>
<td>Programme Costs</td>
<td>4.5</td>
<td>8.2</td>
</tr>
<tr>
<td>Net Savings</td>
<td>13.8</td>
<td>10.1</td>
</tr>
<tr>
<td>Benefit-Cost Ratio</td>
<td>4.1:1</td>
<td>2.2:1</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

Under both estimates of benefits, the eradication programme realises net savings after three years, ranging from **US$4.7 million** to **US$13.8 million**, depending upon the budget scenario chosen. Net savings are predictably higher after ten years, as benefits continue to accumulate beyond the targeted three-year eradication phase. Net benefits are estimated to range between **US$25.5 million** and **US$43.5 million** at the end of ten years. Benefit-cost ratios for all scenarios and time periods are correspondingly greater than one indicating the economic feasibility of the project investment under varying assumptions of benefits and programme costs.
In sum, benefits to producers would more than offset the programme cost almost immediately, given that full benefits ranging from US$5 million to US$8 million annually would be realised by the end of the second year of eradication. Out of the five categories of loss attributable to screw-worm estimated in this study, the greatest savings would be realised in terms of the reduction in the cost of livestock production. The labour required for surveillance and the use of insecticides to control screw-worms have resulted in high recurrent costs. These costs are necessary tradeoffs toward minimising production losses. With eradication of the pest, these additional resource expenditures could be redirected to other investment activities. Based on increases in the cost of production of about US$5 million, the additional cost per animal is estimated to be US$5 for inspection and treatment-related costs.

Benefits from screw-worm eradication have important implications for Jamaica, in the light of the large distribution of subsistence farmers dependent upon small-animal holdings for their food source. The gains that could be potentially achieved in Jamaica serve as a compelling argument for the extension of the eradication initiative to the remaining endemic islands of the Caribbean. In addition to lessening the risk of re-infestation to pest-free areas, countries such as Haiti and the Dominican Republic could realise significant gains proportionate with their large livestock populations.

REFERENCE

The Vector Control Operations in the Onchocerciasis Control Programme in West Africa

Jean-Marc Hougard

Institut Francais de Recherche Scientifique pour le Developpement et Cooperation, Vector Control Unit, Onchocerciasis Control Programme, P.O. Box 549, Ouagadougou, Burkina Faso

INTRODUCTION

Onchocerciasis is a dermal filariasis transmitted to man by a blood sucking blackfly belonging to the Simulium genus. The most serious manifestations of the disease are blindness and debilitating skin lesions. Africa is by far the most affected continent both in terms of distribution and severity of the clinical manifestations of the disease. That is the reason why an ambitious regional onchocerciasis control project, the Onchocerciasis Control Programme in West Africa (OCP), was launched in 1974 (Molyneux 1995). The objective is to eliminate onchocerciasis as a public health problem and as an obstacle to socio-economic development and to ensure that the countries are in a position to maintain these achievements. Seven countries were concerned at the beginning of the programme (Figure 1), delimiting the "initial area" (Bénin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, Niger and Togo). In 1988, the OCP began operations in the "western extension", an additional four countries in the West (Guinea, Guinea Bissau, Senegal and Sierra Leone) and extended operations into the "southeastern extension" (south Bénin, Ghana and Togo). The rationale for these extensions related to findings that the vectors were able to migrate and hence re-invade controlled areas over several hundred kilometres (Garms et al. 1979). Until 1989, in the absence of a non-toxic drug which could be used on a wide scale to kill the adult worm, the vector control strategy was the only method to interrupt the transmission of the blinding form of the parasite until the adult worm in the human body was eliminated (the maximum duration of the adult worm is estimated to be about fourteen years). In the late 1980s, ivermectin, a microfilaricide which is the only drug available to date, became an integral part of the OCP control strategy (Webbe 1992). In the extension areas, larviciding is still going on with satisfaction, combined with the distribution of ivermectin. In pursuing this combined therapeutic and vector control strategy, the whole of the basins treated should be freed from blinding onchocerciasis by the year 2002 at the latest, which is the end point of the programme activities.

THE VECTOR CONTROL ACTIVITIES

Vector control activities consist of treating with insecticides the rivers where larval stages of the vector, Simulium damnosum Theobald s.l., breed. Taking into account that the development of the aquatic stage which, from egg to pupae, hardly exceeds one week, the spraying is done on a weekly basis. In addition to this, the large number of breeding sites (actually over 15,000 km of river in the rainy season) and the difficulties to reach some of these sites by ground, explain why the aerial spraying method has been chosen. Vector control has encountered three major obstacles which
have been successfully overcome. First, it was clearly established very early that the border of the treated area (654,000 km² spread over seven countries) was re-invaded by infective blackflies from regions outside the programme area. In order to protect permanently the original area and also clean the basins at the source of the re-invasions, the incriminated hyperendemic regions were identified and then put under larvicidal treatment. The second obstacle was the emergence, five years after the beginning of the programme, of a resistance of *S. damnosum* s.l. to temephos (Guillet et al. 1980). The compound (organophosphate) was the only insecticide used at the beginning of the programme. It was selected because of its efficacy, the distance over which it remains effective, its lack of impact on non-target fauna and also its acceptable cost. When the development of resistance to another organophosphate (chlorphoxim) was discovered thereafter, the programme hence adopted a strategy of rotational use of insecticides, where possible, from different chemical groups, with different modes of action, to slow down and to suppress the appearance of new cases of resistance (Hougard et al. 1993).

---

**Figure 1. Onchocerciasis Control Programme in West Africa.**

Seven insecticides are currently in use. Six of them are chemicals formulated as emulsifiable concentrates (temephos, phoxim, pyraclofos, permethrin, etofenprox and carbosulfan) while the seventh is a liquid concentrate of a biological insecticide (*Bacillus thuringiensis* H-14 or *B.t.* H-14). This rotational use of insecticides has been so effective that, currently, there is very little resistance left to the organophosphates in use while the susceptibility of the *Simulium* population to other compounds remains unchanged. The third obstacle to be dealt with was of environmental concern (Lévêque 1989). A blackfly larvicide, no matter how effective it is, could not be accepted for use by OCP if it had a short, an intermediate or a long-term deleterious effect on the environment. Temephos and *B.t.* H-14 are considered harmless to the environment and can be used without any particular restriction. On the other hand, pyraclofos may, in
case of accidental overdose, show some toxicity against the non-target fauna, namely fish, and for that reason, it is not for use under water discharge of 15 m$^3$/s. Permethrin and carbosulfan should also be used with precaution, never below 70 m$^3$/s and, if possible, for not more than six weeks per year on the same river stretch. As the toxicity of etofenprox for fishes and crustaceans is lower than permethrin, its use is allowed to discharges above 15 m$^3$/s but without any restriction on the number of annual cycles. In general, all chemical insecticides should be used in such a way as to avoid any overdose that is likely to cause harm to the environment. For this reason, the programme has set up a satellite transmission network for recording water discharge allowing for in-time management of hydrological data in the treatment of the rivers (Servat and Lapetite 1990). In addition to this, treatment helicopters are equipped with a spraying system that allows for dosing of quantities of insecticides with an accuracy of around one centilitre.

THE STRATEGY IN THE INITIAL AREA

Before the launching of the programme, the initial area was plagued mainly with the most severe form of onchocerciasis, the "savanna" type, which is characterised by a high incidence of blindness, and is transmitted by the group of "savanna-dwelling" species of the *S. damnosum* complex. In its principle, the vector control strategy in the initial area was thus simple to implement as it consisted in arresting transmission of the parasite regardless of its pathogenicity, through the elimination of its vector regardless of the species involved (Le Berre et al. 1979). From 1990, the first decisions to definitively stop larviciding were made for the basins in which the situation seemed to be satisfactory, both from the epidemiological and entomological points of view. Now, onchocerciasis is no longer a public health problem in the whole of the initial area. Nevertheless, despite the long duration of vector control activities, a few foci of infections remain, even if the clinical signs of the disease have totally disappeared (Boatin et al. 1997). Although these foci represent a negligible percentage of the oncho-free area, their persistence remains a cause for concern. Indeed, a risk of contamination of the adjacent basins is always possible and there is no guarantee that an alternative control strategy will succeed where the current strategy has partially failed. Therefore, the programme and the participating countries are paying particular attention to these foci so as to identify the factors which have hindered the success of control operations. To date and in the present state of our investigations, a succinct analysis of the residual onchocerciasis foci remaining in the original area allows for the identification of three main obstacles to a good achievement of vector control operations. One is a seasonal contamination by wind assisted migrating infective blackflies from hyperendemic areas. The second is linked to migrations of infected human populations coming from prevailing endemic areas. Another factor is the difficulty of accessibility to the area under control, resulting in an incomplete treatment of the breeding sites or in an inadequate entomological assessment network. The discovery of the characteristic features of these foci has made it possible to take a number of corrective actions principally based on the use of ivermectin. Indeed, a long-term control of morbidity through community directed distribution of ivermectin is the most reasonable solution. This method of distribution, which was retained by the African Programme for Onchocerciasis Control (APOC), directly involves the exposed communities (Dadzie 1997). In the present socio-economic context, this approach is probably the best way of ensuring the optimal and durable protection of the populations after the OCP ends.
THE STRATEGY IN THE EXTENSION AREAS

The extension zones under larviciding are characterised by different types of vegetation ranging from the Sudanese and Guinean savanna to degraded forests. This diversity of landscape favours the presence of various habitats conducive to the development of all species of the *S. damnosum* complex, from the savanna-dwelling vectors to the main forest-dwelling ones. At the time of institution of the larvicide treatments, the idea of using a selective strategy exclusively targeted at the savanna-dwelling blackflies had been considered. However, the mechanism of transmission under natural conditions was not clearly understood because of the inability to distinguish between the strains of the parasite and the difficulty in accurately determining the identity of the adult infected females. This option was therefore discarded in favour of a less targeted strategy taking into account, thanks to the cytotaxonomic tools available (Crosskey 1987), the seasonal abundance of the savanna blackflies in their larval habitat. To date, the technique of morphological identification of adult blackflies has improved, making it now possible to differentiate the savanna species from the others at the same catching point (Wilson et al. 1993). The use of DNA probes allows for the differentiation of the savanna strain from the forest strain of the parasite and another technique allowing for the identification of the adult flies is being developed. These new methods are shedding further light on the mechanisms of transmission under natural conditions, showing that the link of savanna-dwelling vectors with the blinding strain of the parasite is not as close as suggested by the results of the xenodiagnostic studies conducted in the context of experimental transmissions (Toé et al. 1997). However, many other observations made in several basins of the extension areas suggest that the current strategy can be maintained without jeopardising the achievements of vector control. These differing observations led to uncertainties regarding the threat the "blinding" strain of the parasite represents in the extension areas. To attempt to know better, research is oriented in two directions. The first orientation, which is under way, is attempting to improve the performance of the molecular tools (microsatellites, heteroduplex) to allow for a still finer identification of the vector and parasite populations. The second orientation, which is at the planning stage, will call upon immunodiagnostic techniques. It will try to determine whether there exist different levels of pathogenicity in the parasite or, in man, any predispositions to develop blinding onchocercal lesions or not. Pending these results, and four years to the definitive cessation of larvicide treatments, the current vector control strategy which is a realistic compromise between an "overselective" option and, at the other extreme, a too "global" option, should be pursued without any major change until the conclusion of the programme. For the time being, vector control, combined with ivermectin distribution, is continuing in almost all of the basins of the extension areas. However, in a few river basins where the blinding strain of the parasite holds sway, transmission sometimes remains difficult to control despite continued larviciding and the distribution of ivermectin. As in the cases observed in the initial area, unsuspected transmission may subsist here and there and the possibility of a few residual foci of "savanna" onchocerciasis subsisting after the end of the programme cannot be excluded. In the absence of vector control measures and since a macrofilaricid is not suitable for mass treatment, ivermectin will also remain the only means of control of these residual foci after the year 2002.
THE TRANSFER OF RESIDUAL ACTIVITIES

In less than five years, the residual activities of the Onchocerciasis Control Programme in West Africa will be fully in the hands of the participating countries. A few residual foci will still subsist both in the original and in the extension areas. However, their total size will remain fairly small compared to the 25 million hectares of fertile valleys which will be made free from the disease by the end of the programme. Nevertheless, the emergence of new onchocerciasis foci after 2002 in the areas considered to be freed cannot be excluded. Whatever the situation, the countries must be provided with the means to detect any onchocerciasis focus early before it becomes too difficult to control. As far as entomological surveillance is concerned, the necessary tools and know-how will be made available to the national health services to enable them to detect any transmission. For that purpose, a simple and cheap method of detection of the infective larvae of the parasite in blackflies is in the process of being operationalised (Yameogo et al. 1997). Thanks to this method, the countries will be able to mobilise themselves even before a recrudescence of the infection in man, which is more difficult to control, is detected, through the various techniques currently available or in the process of becoming so. Finally, as far as vector control is concerned, all the activities will have probably ceased (Hougard and Sékétéli 1998). However, larviciding from the ground with non-toxic and non-persistent insecticides to control blackfly nuisance could increase, at least in those sites of socio-economic interest, where an efficient and sustainable management of such treatments can be ensured (Hougard et al. 1997).

ACKNOWLEDGEMENTS

All my thanks goes to Sammy Sowah, a professional staff member of the OCP, in reading the English version of this manuscript.

REFERENCES


Progress in the Eradication of *Amblyomma variegatum* Fabricius, 1794 (Ixodoidea, Ixodidae) from the Caribbean

R.G. Pegram¹, E.F. Gersabeck², D.D. Wilson² and J.W. Hansen³

¹ Caribbean Amblyomma Programme, Food and Agriculture Organization, Barbados
² United States Department of Agriculture, Animal and Plant Health Inspection Service, 4700 River Road, Riverdale, Maryland 20737, USA
³ Food and Agriculture Organization, Animal Health Service, Viale delle Terme di Caracalla, 1-00100 Rome, Italy

INTRODUCTION

*Amblyomma variegatum*, commonly known as the tropical Bont tick, was introduced from West Africa to the islands of Guadeloupe and Antigua in the 19th century. The tick spread only to two other islands in the French West Indies during the following 70 to 80 years. Since the mid-1970s, however, it became widely distributed in the eastern Caribbean islands (Figure 1). There is now increasing evidence that migratory birds, especially the cattle egret, *Bubulcus ibis* Linnaeus (Ciconiformes: Ardeidae) disseminated larvae and nymphs, as the egret itself has been spreading to new islands over the last 20 years (Corn et al. 1993, Barre et al. 1995). Subsequently, the tropical Bont tick, through its association with the bacterial skin disease known as dermatophilosis, caused the loss of large numbers of animals. On Nevis, for example, cattle numbers were decimated from 5,000 to 500 in less than 10 years. Elimination of this tick and its associated diseases could help to alleviate the deficit in animal protein in the region which imports about US$100 million worth of livestock products per annum.

![Figure 1. Distribution of Tropical Bont Tick – Eastern Caribbean Islands.](image-url)
Risk analysis, feasibility and cost-benefit studies were carried out to assess the importance of these problems (Alderink and McCauley 1988, Gersabeck 1994). The US Department of Agriculture estimated potential losses of US$762 million annually if the tick and its associated diseases became established in mainland countries. These studies led to the formulation of the Caribbean *Amblyomma* Programme in the late 1980s (Barre and Garris 1989, CARICOM/FAO/IICA 1995, Wilson 1996). During the early 1990s, potential donors were concerned about the proposed tick control strategy whereby government veterinary teams would be responsible for treatment of all livestock. Based on practical experience in the region, it was considered particularly unrealistic for teams to treat 600 - 1,000 animals per day under the current livestock management practices. An alternative, or complementary, method proposed the use of mobile crush-pens which would also be difficult to implement. Who would erect them and where? Once erected, who would bring the animals to them? Most livestock in the region are owned by part-time farmers who tend their livestock early in the morning or late in the evening or on weekends. Consequently, they are rarely available to assist veterinary personnel in handling their livestock during normal working hours. This unique system of animal ownership and husbandry practices in the Caribbean would, therefore, due to very high operational costs, almost prohibit conventional delivery of tick control by veterinary services personnel.

**A NEW APPROACH**

For the tick eradication process to be cost-effective and sustainable, the programme regional coordinating unit considered it necessary to modify the methodology originally proposed, and to impose upon livestock owners the responsibility of treating their own animals. Fortunately, the eradication process is based upon a simple biweekly application of the pour-on acaricide Bayticol for a minimum of two years (Barre et al. 1993). There remained, however, some concern regarding farmer compliance as it had been noted that "... whilst the technology was available and eradication was considered to be feasible, the most important obstacle in attempts to eradicate the tropical Bont tick would be the human factor". Thus, the revised approach would require Caribbean livestock owners to adopt new animal husbandry practices, and in order to keep them informed and motivated to follow the treatment schedules, an intensive public awareness campaign was implemented based upon experiences in other animal health programmes (Villet 1994).

**IMPLEMENTATION AND FINANCE**

The multi-donor Caribbean *Amblyomma* Programme became operational at the end of 1994. It is a regional Caribbean Community (CARICOM) programme jointly implemented by the Food and Agriculture Organization (FAO) and the Inter-American Institute for Cooperation on Agriculture (IICA). Overall policy guidance is provided by the *Amblyomma* Programme Council, whose membership is comprised of donor representatives, technical agencies, CARICOM and government representatives.

The overall estimated total cost of the tropical Bont tick eradication programme is approximately $37 million for both the CARICOM and the French territories. The programme will take about five years to complete and includes the following components:
National projects in the CARICOM region, with an overall cost of US$15.6 million, are supported by direct farmer inputs to the value of US$8.2 million, government funds (US$2.9 million) and donor contributions (US$4.5 million).

The CARICOM regional coordination project includes responsibility for training and production of promotional materials for use in the national projects as well as expenditure for training, travel, support costs and overall coordination through the *Amblyomma* Programme Council (APC). Estimated cost is about US$5.5 million.

The cost of the French West Indies programme, which is managed independently, is estimated at about US$17 million, which is secured through funds from the French government and the European Union.

A summary of current donor funding is shown in Table 1. USDA continues its long-term commitment to the programme with a pledge for an additional year to 2001. FAO continues to source additional trust funds and donor funds, but has continued its commitment through the FAO Technical Cooperation Programme and the IFAD technical assistance grant. National governments, through CARICOM and FAO, are now negotiating with the European Union (EU) for additional financial support, under the Lome IV programme for 1998-2000, to purchase tick control chemicals and support the continuation of the extension, training and communications component.

### Table 1. Summary of Current Donor Funding (in US$ million).

<table>
<thead>
<tr>
<th>Donor/Government</th>
<th>Committed</th>
<th>Requested</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>IICA/USDA</td>
<td>2.20</td>
<td>0.90</td>
<td>3.10</td>
</tr>
<tr>
<td>IICA</td>
<td>0.18</td>
<td>0</td>
<td>0.18</td>
</tr>
<tr>
<td>IICA/USDA Sub-total</td>
<td>2.38</td>
<td>0.90</td>
<td>3.28</td>
</tr>
<tr>
<td>FAO/TF:ODA/GTZ</td>
<td>0.75</td>
<td>0</td>
<td>0.75</td>
</tr>
<tr>
<td>FAO/TF: USDA/SECNA</td>
<td>0.20</td>
<td>0</td>
<td>0.20</td>
</tr>
<tr>
<td>FAO/TF/Other</td>
<td>0</td>
<td>0.57</td>
<td>0.57</td>
</tr>
<tr>
<td>FAO/TF:BEL/ITA (APO Staff)</td>
<td>0.20</td>
<td>0</td>
<td>0.20</td>
</tr>
<tr>
<td>FAO/TF:NET (APO Staff)</td>
<td>0.32</td>
<td>0.08</td>
<td>0.40</td>
</tr>
<tr>
<td>FAO/TF: IFAD</td>
<td>1.00</td>
<td>0</td>
<td>1.00</td>
</tr>
<tr>
<td>FAO/TCP (Regional Communications)</td>
<td>0.29</td>
<td>0</td>
<td>0.29</td>
</tr>
<tr>
<td>FAO/TCP (Barbados)</td>
<td>0.30</td>
<td>0</td>
<td>0.30</td>
</tr>
<tr>
<td>FAO Sub-total</td>
<td>3.06</td>
<td>0.65</td>
<td>3.71</td>
</tr>
<tr>
<td>EU/CARIFORUM (FAO)</td>
<td>0.90</td>
<td>2.10</td>
<td>3.00</td>
</tr>
<tr>
<td>Total</td>
<td>6.34</td>
<td>3.65</td>
<td>9.99</td>
</tr>
</tbody>
</table>

A regional coordinating unit assists in overall management of the programme and coordinates the four main components:
• Administrative management.
• Eradication and surveillance.
• Extension, training and communication.
• Adaptive research.

The main tasks of the regional coordinating unit are to support national efforts in tick control in the infested countries in the following areas:

• Providing policy advice to governments on legislation and quarantine.
• Strengthening veterinary services (livestock census and animal registration).
• Purchasing and distributing acaricide and other equipment and supplies.
• Training veterinary personnel in monitoring and surveillance.
• Providing and maintaining a regional CAP database.
• Increasing public awareness and motivation among livestock owners.
• Training in public information and communication techniques.

Government veterinary staff are responsible for the following activities:

• Registering all livestock owners.
• Registering, and where appropriate, tagging all animals.
• Maintaining a national data base.
• Training farmers in the correct use of Bayticol.
• Distribution of Bayticol.
• Monitoring the eradication process.
• Carrying out surveillance for the tropical Bont tick.

These activities are supported by extension and communications staff in order to reinforce compliance with the treatment schedules.

ADAPTIVE RESEARCH

An important, new adaptive research component, supported by the International Fund for Agriculture Development (IFAD), aims to evaluate alternative, and adjunct, cost-effective and environmentally friendly control technologies. Equally important during the post-treatment follow-up phase, is the availability of improved surveillance methods that do not jeopardise the level of eradication achieved on each island. The adaptive research work plan includes the following field studies to determine the efficacy of various acaricide formulations and novel methods of application, and biological agents to control the tropical Bont tick:

• ACATAK®, a growth development inhibitor.
• Duncan and other self-medicating applicators.
• Pheromone/acaricide-impregnated decoy ear and tail tags.
• Biological control using parasitoids (Ixodiphagus hookeri) and "myco-insecticides" (Beauveria bassiana (Balsamo) Vuillemin and Metarhizium anisopliae (Metchnikoff) Sorokin).
RESULTS AND DISCUSSION

Despite the uncertainty of long-term funding, encouraging results have been achieved since the launch of eradication activities in Anguilla, St. Kitts and Nevis (1995), Montserrat and St. Lucia (1996), and Antigua and Barbados (1997). The number of livestock registered and under treatment is summarised in Table 2. The active participation of the livestock owners on all islands has been encouraging. Both tick populations (Table 3) and the prevalence of dermatophilosis (Figure 2) have been reduced markedly over the past two years.

Table 2. Status of Registration and Treatment (Targeted) by Country (as of February 1998).

<table>
<thead>
<tr>
<th>Country [Owners]</th>
<th>Cattle</th>
<th>Sheep and Goats</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated</td>
<td>Targeted</td>
<td>Estimated</td>
</tr>
<tr>
<td>Anguilla [597]</td>
<td>100</td>
<td>100</td>
<td>6,500</td>
</tr>
<tr>
<td>Antigua [1436]</td>
<td>12,000</td>
<td>11,094</td>
<td>54,400</td>
</tr>
<tr>
<td>Barbados [364]</td>
<td>12,500</td>
<td>1,600</td>
<td>44,000</td>
</tr>
<tr>
<td>Dominica [?]</td>
<td>3,400</td>
<td>1,090</td>
<td>15,100</td>
</tr>
<tr>
<td>Montserrat [?]</td>
<td>1,000</td>
<td>1,090</td>
<td>1,300</td>
</tr>
<tr>
<td>St. Kitts [761]</td>
<td>2,700</td>
<td>2,700</td>
<td>9,500</td>
</tr>
<tr>
<td>Nevis [742]</td>
<td>541</td>
<td>541</td>
<td>27,900</td>
</tr>
<tr>
<td>St. Lucia [458]</td>
<td>13,000</td>
<td>1,050</td>
<td>22,500</td>
</tr>
</tbody>
</table>

Table 3. Qualitative and Quantitative Surveillance for A. variegatum (TBT) in 1997.

<table>
<thead>
<tr>
<th>Country [Owners]</th>
<th>Animal Populations, Number Examined and Tick Sightings</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cattle</td>
<td>Sheep and Goats</td>
</tr>
<tr>
<td></td>
<td>Population</td>
<td>Examined</td>
</tr>
<tr>
<td>Anguilla [597]</td>
<td>100</td>
<td>8</td>
</tr>
<tr>
<td>Antigua [1436]</td>
<td>12,000</td>
<td></td>
</tr>
<tr>
<td>Barbados [364]</td>
<td>12,500</td>
<td>2 (sites)</td>
</tr>
<tr>
<td>Dominica [?]</td>
<td>3,400</td>
<td>2 (sites)</td>
</tr>
<tr>
<td>Montserrat [?]</td>
<td>1,000</td>
<td></td>
</tr>
<tr>
<td>St. Kitts [761]</td>
<td>2,700</td>
<td>318</td>
</tr>
<tr>
<td>Nevis [742]</td>
<td>541</td>
<td>0</td>
</tr>
<tr>
<td>St. Lucia [458]</td>
<td>13,000</td>
<td>1 (site)</td>
</tr>
</tbody>
</table>
CONCLUSIONS

The mid-term review/evaluation report (George et al. 1997) concluded that incredible progress had been made towards the achievement of the goal, despite resource, technical, and personnel constraints. The approach which relied on farmers for the treatment of animals was highly commended. The public information and communication strategy reinforced the technical veterinary component of the programme. It was further concluded that the approach was cost-effective and sustainable and will contribute to the greater involvement of farmers in future livestock improvement programmes.

The review emphasised that the progress would only be sustained if additional funding be secured to finance the eradication of *Amblyomma variegatum* from the entire Caribbean. It recommended that an updated, coordinated Caribbean plan for the eradication programme be prepared and approved with input from all participating countries. A project proposal was prepared and forms the basis of the application to the European Union for further support.

ACKNOWLEDGEMENTS

Technical and scientific support of both national and regional coordination unit staff is gratefully appreciated. The authors acknowledge the technical and financial
assistance provided by the national governments of Anguilla, Antigua, Barbados, Dominica, Montserrat, St. Kitts and Nevis and St. Lucia. Financial support provided by international donors (the USDA, IFAD, IICA, the EU, FAO, and the governments of Belgium, Germany, Italy, the Netherlands, and the United Kingdom) is gratefully acknowledged. Additional sponsorship was kindly provided by Bayer, AG Germany, and various sponsors in the CARICOM countries, particularly in St. Lucia.

REFERENCES


Area-Wide Control of Chagas Disease Vectors in Latin America

C.J. Schofield

ECLAT Coordinator*, LSHTM, London WC1 E7HT, United Kingdom

Chagas disease (American trypanosomiasis) is now ranked by the World Bank as the most serious parasitic disease of the Americas, with a medical and economic impact far outranking even the combined effects of other parasitic diseases such as malaria and schistosomiasis (World Bank 1993). The infection is virtually impossible to cure and the disease is difficult and costly to treat. In contrast, transmission can be halted by eliminating the domestic insect vectors – large blood sucking reduvids of the subfamily Triatominae – and by improved screening of blood donors to minimise the risk of transfusional transmission (WHO 1991).

Improved screening of blood banks requires appropriate legislation backed by a well-developed system of reference laboratories and standardised procedures, although to a large extent, this can be implemented in a progressive way from local to national levels (Schmunis 1991). By contrast, the key to success in Chagas disease vector control lies in the implementation of large-scale regional or international programmes coupled with long-term community-based vigilance. This is a classic intervention model beginning with a vertical intervention, the attack phase, in which all infested houses are sprayed by trained professionals, progressively backed by a more horizontal community-based system where householders themselves can report the presence of any residual infestations for retreatment where necessary. Elimination of domestic vectors of Chagas disease is facilitated by their slow reproductive rates and limited genetic variability, but is hampered by the ease of passive transport of the insects from one house to another, even across state and international boundaries (Schofield 1994). For this reason, international collaboration is particularly important in Chagas disease vector control.

Since early trials in the 1940s, there have been many local and regional campaigns designed to control domestic populations of Triatominae, especially in Argentina, Brazil and Venezuela. Without exception, the results followed a similar course, with a rapid decline in house infestation rates and a reduction in the incidence of human infection. Generally however, it was impossible to consolidate the initial successes due to changes in intervention policy and a corresponding lack of programme continuity. Although domestic populations of Triatomine bugs can be cleared from individual houses, or from particular localities, the houses remain vulnerable to re-infestation by bugs brought in from untreated regions. In Brazil, the national programme to eliminate the primary vector, *Triatoma infestans* (Klug), was launched in 1983. It was highly successful, but – as with previous local campaigns – there were problems of sustainability and re-infestation of many of the treated localities (Dias 1987).

*The European Community – Latin America research network on the biology and control of Triatominae (ECLAT) is supported by the European Commission and the AVINA Foundation of Switzerland.
To address this problem, governments of the six southern cone countries (Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay) in 1991 set up a joint initiative to control Chagas disease through the elimination of all domestic and peridomestic populations of the triatomine vectors (Kingman 1991). With the addition of Peru to this programme in 1996, the initiative now covers the entire geographic distribution of the primary vector, *T. infestans*. The Southern Cone Initiative was planned as a 10-year programme to eliminate all domestic and peridomestic populations of *T. infestans*, with concurrent suppression of other vector species of local importance. Now just past its mid-point, the programme has already met with considerable success with Chagas disease transmission interrupted over vast areas of Argentina, Chile, Uruguay, central Brazil, eastern Paraguay and southern Bolivia (Schmunis et al. 1996, WHO 1996, 1997a, 1998). Other domestic vectors in the region – such as *Triatoma brasiliensis* Neiva in northeast Brazil – are also being controlled and the World Health Organisation (WHO) now predicts complete interruption of Chagas disease transmission by the year 2000 (WHO 1997b). Programme costs were originally estimated at US$190-350 million over the 10-year period, with most of the investment to be committed during the initial attack phase over the first 3 years. On this basis, the internal rate of return of the programme was predicted to be just over 14% (Schofield and Dias 1991,1999). In fact, investment to date has been just over US$200 million and recent studies in Brazil and Argentina have revealed economic rates of return in excess of 30% and 60%, respectively (Akhavan 1996, Basombrio et al. 1998).

The Southern Cone Initiative has also spurred other regions to plan similar programmes, notably the recently announced Central American Initiative to eliminate *Rhodnius prolixus* Stahl from El Salvador, Guatemala, Honduras and Nicaragua and the Andean Pact Initiative for the control of *R. prolixus* and other vectors in Colombia and Venezuela. In Central America at least, *R. prolixus* seems to be exclusively domestic with a very restricted genetic repertoire and is considered a particularly vulnerable target for control (Dujardin et al. 1998). In Andean Pact countries however, the status of silvatic *R. prolixus* remains unclear and urgent studies have been initiated to assess rates of gene flow and population dispersal between silvatic and domestic habitats (Schofield and Dujardin 1997).

With successful control or elimination of *T. infestans* and *R. prolixus* and control of sympatric vectors, a figure approaching 70% of Chagas disease transmission will be interrupted, while large-scale improvements in blood bank screening will interrupt a further 10-15%. But maintenance of this success and further progress, will depend very largely on improved systems of entomological surveillance and these in turn will depend crucially on maintaining political continuity for the control and surveillance programmes. Although technologically simple, the administrative scale of the regional Chagas disease control initiatives has revealed major complexities and intervention coverage has not been entirely uniform. In each country the programmes have faced difficulties primarily of an administrative nature, especially as each country has simultaneously sought to decentralise its intervention services producing inevitable disruption to the chain of operational decisions and lapses in entomological surveillance. Already there are indications of little-known species of Triatominae adapting to new domestic habitats and our understanding of this evolutionary process is still in its infancy. It should not be forgotten – especially by those responsible for budgetary priorities – that the domestication of Triatominae and initiation of Chagas disease transmission is a relatively recent phenomenon. Experience shows that we can now combat this, but if we relax vigilance, it could happen again.
REFERENCES


Large-Scale Control of Mosquito Vectors of Disease

C.F. Curtis and M.H. Andreasen

London School of Hygiene and Tropical Medicine, London WC1E 7HT, United Kingdom

MOSQUITO BORNE DISEASE

By far the most important vector borne disease is malaria transmitted by Anopheles mosquitoes causing an estimated 300-500 million clinical cases per year and 1.4-2.6 million deaths, mostly in tropical Africa (WHO 1995).

The second most important mosquito borne disease is lymphatic filariasis, but there are now such effective, convenient and cheap drugs for its treatment that vector control will now have at most a supplementary role (Maxwell et al. 1999a). The only other mosquito borne disease likely to justify large-scale vector control is dengue which is carried in urban areas of Southeast Asia and Latin America by Aedes aegypti L. which was also the urban vector of yellow fever in Latin America. This mosquito was eradicated from most countries of Latin America between the 1930s and 60s but, unfortunately in recent years, it has been allowed to re-infest and cause serious dengue epidemics, except in Cuba where it has been held close to eradication (Reiter and Gubler 1997).

In the 1930s and 40s, invasions by Anopheles gambiae Giles s.l., the main tropical African malaria vector, were eradicated from Brazil (Soper and Wilson 1943) and Egypt (Shousha 1947). It is surprising that greatly increased air traffic has not led to more such invasions of apparently climatically suitable areas, e.g., of Polynesia which has no anophelines and therefore no malaria.

The above mentioned temporary or permanent eradications were achieved before the advent of DDT, using larvicidal methods (of a kind which would now be considered environmentally unacceptable) carried out by rigorously disciplined teams.

THE ATTEMPT TO ERADICATE MALARIA

Between the end of the Second World War and the 1960s, the availability of DDT for spraying of houses allowed eradication of malaria from the Soviet Union, southern Europe, the USA, northern Venezuela and Guyana, Taiwan and the Caribbean Islands, apart from Hispaniola. Its range and intensity were also greatly reduced in China, India and South Africa and, at least temporarily, in Sri Lanka. In several Latin American countries much progress was made, but this has been reversed following the abandonment of DDT without any replacement being brought into use (Roberts et al. 1997). After eradication from the Soviet Union in the 1960s, malaria epidemics are now returning to Azerbaijan and Tadzikistan following the collapse of the health system and the descent into civil war (Nikolaeva 1996).

In a few instances, unlooked-for eradication has been claimed to have occurred locally as a result of DDT house spraying of species which are strongly endophilic, i.e., with a strong tendency to rest in houses. Examples are of Anopheles funestus Giles from Mauritius and possibly from Zanzibar and Pemba (Gillies and de Meillon 1968). There had been plans to eradicate the vector population from Sardinia (Logan 1953), but it was
eventually found to be unfeasible and also unnecessary for the eradication of the disease. As emphasised by MacDonald (1957), a moderate reduction in the probability of daily survival may be enough to reduce almost to zero the proportion surviving the 12 days required for completion of development of malaria parasites in the mosquito, and thus malaria transmission may die out. This view was borne out by the collapse of malaria in, for example, Italy, when DDT was brought to bear on it (Merzagora et al. 1996). On this basis, many (but not all) experts advised WHO to go ahead with a world-wide attempt at malaria eradication. It is usual to ascribe its failure in most parts of the tropics to insecticide resistance, and this did make some contribution. However, more important factors were lack of resources and political will and the saturating levels of malaria transmission in many parts of lowland Africa, leading to the requirement for very high percentage reductions in transmission rate if any real progress was to be made. This also means that if a small percentage of individuals in the vector population are consistent in choosing not to enter and rest in houses, this fraction which cannot be killed by domestic insecticides may be enough to maintain an almost unchanged level of malaria prevalence (Molineaux and Gramiccia 1980).

Another aspect of this problem, which was raised in the early discussions about the feasibility of eradication of malaria in Africa and has recently been raised again (Trape and Rogier 1996, Snow et al. 1997), is the negative feedback effect of immunity. In areas of high transmission, the human population only survives by acquisition early in life of a moderate degree of immunity, at the expense of suffering much severe illness and much infant mortality. It has been argued that a moderate reduction of transmission, by reducing the rate of acquisition of immunity, would delay the onset of malaria attacks until later in life. This could reduce the net lifetime benefit of the vector control efforts and could even render them counterproductive if, as some believe, the risk of cerebral malaria is highest not in infants, but in children without adequate acquired immunity. This vitally important issue is difficult to settle within the bounds of medical ethics (Molineaux 1997). Theoretically, the problem could be avoided by replacing the missing immunity by a vaccine, when it becomes available, or by eradicating the vector population so that the missing immunity could do no harm. The possibility of eradication of an *Anopheles* population by SIT will be discussed below.

**IMPREGNATED BEDNETS**

Most malaria infective bites by *Anopheles* mosquitoes occur at hours when people are in bed (88% of such bites between 2200 and 0500 hrs according to a recent study in Tanzania by Maxwell et al. 1998). Bednets without chemical treatment provide some degree of protection against malaria infection (about 33% reduction in incidence of re-infection in Tanzanian children cleared of their pre-existing infection by drug treatment (Maxwell et al.1999b). This can be boosted to about 83% protection with either of two pyrethroid treatments of the nets (Maxwell et al. 1999b). In fact, treatment of nets can be considered a more targeted way of using insecticide than spraying it on walls and ceilings and hoping that mosquitoes will rest on it. Mosquitoes are attracted to bednets by the body odour and/or carbon dioxide emitted by the occupants. Pyrethroids are currently the only class of insecticide used on bednets, but in view of the threat of pyrethroid resistance in *Anopheles* (Vulete et al. 1996, Darriet et al. 1997, Curtis et al. 1998b), it is important that satisfactory non-pyrethroid alternatives are found. Despite the cheapness of DDT per unit weight, impregnated bednets are preferable to DDT spraying because:
• they are more effective against malaria (Kere et al. 1996),
• at the dosages of each type of insecticide which are needed, pyrethroid treatment of nets is cheaper per family protected (Li 1990, Kere and Kere 1992, Xu et al. 1998),
• pyrethroids are biodegradable but DDT is not, and residues of it derived from house spraying have been found in human breast milk (Bouwman et al. 1990), though whether this is harmful remains to be proved, and
• DDT intended for anti-malaria use may illicitly find its way into agriculture, and may produce residues in crops which make them unacceptable to importers (Curtis 1994).

A comparison between pyrethroids used for bednet impregnation and for house spraying in an area of intense transmission in Tanzania (Curtis et al. 1998a) showed very similar effects of each form of vector control on the mosquito populations, incidence of malaria infection and prevalence of anaemia (one of the main routes by which malaria causes death or chronic ill health). However, because of the six times greater amount of a relatively expensive insecticide required for providing house spraying for a given community, it was concluded that it would be cheaper to provide nets and their treatment. House spraying has always been considered part of the public health service and the urge to try to make poor people pay for their health care has fortunately not yet spread to this form of disease prevention. However, many wish to try to make individual householders pay for nets and insecticide, though switching from free provision of insecticide to selling it (at cost price) led to a drastic fall in percentage coverage of beds by treated nets in Gambia (Cham et al. 1997).

Apart from the effect of treatment of nets in improving the personal protection which they provide, studies in Tanzania (Curtis et al. 1998a) have shown that a major part of the benefit of a community-wide programme with treated nets is the attraction and killing of a large percentage of the vector population so that few survive to an age at which they can become infective. Thus, it is in the interests of the rich to help the poor to acquire treated nets (e.g., via taxation and a public health system) as it would reduce the number of mosquitoes biting the unprotected poor, picking up infection and surviving to threaten the rich if they ever venture out from their own nets during the night.

Extensive trials in four African countries have shown significant reductions in all-cause child mortality as a result of providing treated nets or the insecticide to treat people's own nets (Lengeler et al. 1996). These reductions are comparable to what were achieved in the 1950s with house spraying using dieldrin (Bradley 1991).

Numerous small projects are springing up all over the tropical world on impregnated nets, but so far only in China and Vietnam are treated nets numbered in millions, i.e., on a scale comparable to the heyday of house spraying.

**STERILE INSECT TECHNIQUE**

There was much enthusiasm for SIT for mosquitoes in the 1960s and early 70s but it went into eclipse, largely for political reasons (Anonymous 1975). In the 70s, it was shown in various species of mosquito that chemically sterilised males, or males carrying translocations and a meiotic drive factor or cytoplasmically incompatible with the local population, could compete reasonably well for mates as shown by induction of sterility in the eggs laid by wild females (Lofgren et al. 1974, Grover et al. 1976a, b). An unreplicated report (Bracken and Dondale 1974) that spiders, fed a diet consisting only of
chemosterilised mosquitoes, were sterilised has made radiation sterilisation a more acceptable option. However, there is reduced competitiveness if pupae are irradiated and treatment of adults inactivated by chilling would probably be necessary (Smittle and Patterson 1974).

The problem of immigration of females already inseminated with fertile sperms, and unwilling to mate again, was found to be a major obstacle to progress with SIT against *Culex quinquefasciatus* Say in India (Yasuno et al. 1976). Theoretically, the problem could be solved by large-scale rolling programmes of release. However, finding the capital for this seems unlikely for a programme directed against *Anopheles gambiae* Giles, which extends over huge areas of rural Africa and threatens the lives of the children of the poor, but not cash crops which accountants see as a worthwhile investment.

A more achievable target would seem to be eradication of urban mosquito populations where there is little chance of re-invasion from the surrounding countryside which is occupied by different species ill-adapted to urban life. This argument was first proposed with respect to *Aedes aegypti* in Indian towns (Reuben 1974). With a perceptible decline in confidence in legally enforced or community motivated control of its breeding, there may be a revival of interest in the use of SIT against it. Methods of mass rearing, sex separation to avoid release of biting females and release in urban environments were all developed 25 years ago (Singh et al. 1974).

Among malaria vectors, *Anopheles stephensi* Liston (type form) is the species which maintains urban malaria as an important fraction of India's total malaria problem because this mosquito is well adapted to breeding in water tanks, urban wells and pools of water on building sites. Another form, *An. stephensi mysorensis* Liston, has been described from rural areas (Ramachandra Rao 1984). However, the numbers of ridges on the eggs, which was the original way of defining the two forms, have been found to intergrade (Subbarao et al. 1987). Molecular genetics or chromosome inversions may provide evidence on whether there is gene flow between rural and urban *An. stephensi* and hence, whether rural immigrants would interfere with an urban eradication programme. Urban *An. stephensi* populations can be suppressed (but not eradicated) by rigorous enforcement of larval control by screening water tanks, etc. Any SIT programme against *An. stephensi* should be integrated with such an environmental management campaign, the role of the sterile males being to eliminate the residual population left after the maximum feasible reduction in urban breeding sites.

It is important to avoid release of biting female mosquitoes, and in anophelines (unlike culicines), this unfortunately cannot be done on the basis of pupal size. Genetic sex separation was developed more than 20 years ago for several *Anopheles* species based on translocation of dominant genes for insecticide resistance onto the Y chromosome (Curtis et al. 1976, Seawright et al. 1978). This proved difficult, but was achieved, for *An. stephensi* (Robinson 1986). With most of the translocations there were some crossovers, which broke the male sex linkage of the resistance, but in *Anopheles albimanus* Wiedemann, this was suppressed with a fortunately positioned inversion (Seawright et al. 1978). To select a suitable inversion in a more systematic way, an attempt is in progress to use in situ hybridisation of a probe of the cloned dieldrin resistance gene (ffrench-Constant 1993) to locate where, on the polytene map, this gene is located and hence, where the inversion (induced or naturally occurring) needs to be. If released males were not completely sterile and the population failed to be eradicated, releases might spread the resistance gene. This probably would not matter in the case of resistance to dieldrin as this insecticide is now considered too toxic for anti-mosquito work.
MAKING MOSQUITOES GENETICALLY HARMLESS

Theoretically, the problem for genetic control of continuity between rural populations of species such as *An. gambiae* could be solved (and even become an advantage) if, instead of trying to eradicate with SIT, one aimed to drive genes making mosquitoes harmless through wild populations. Unlike SIT, a gene driving system would not necessarily require large capital investment in a rearing plant nor would it be swamped by a moderate level of immigration. The obvious candidate for a mosquito gene for harmlessness to man would be one for non-susceptibility (refractoriness) to *Plasmodium*, but another possibility would be the gene(s) in *An. quadriannulatus* Theobold (a member of the *An. gambiae* complex) which cause it to bite animals and not humans and therefore prevent it carrying malaria. Several cases of refractoriness have been selected in anophelines (e.g., Collins et al. 1986, Feldmann and Ponnudurai 1989), but all have been due to at least two genes, and it would thus be difficult to link these reliably to driving mechanisms. The recent identification by Billker et al. (1998) of the *Plasmodium* gametocyte activating factor as xanthurenic acid, a product of the metabolic pathway to Diptera eye colour pigments, suggests that a single dominant gene for refractoriness may be obtainable, but it seems that abnormalities in this pathway would have severe fitness costs.

Assuming that a fully fit, single dominant gene for refractoriness is eventually found, the real problem to applying this method remains that of finding a reliable gene driving system. There are precedents in *Drosophila* for the spontaneous spread of certain transposons and of *Wolbachia* symbionts and there is some understanding of under what conditions they would spread (Kidwell and Ribeiro 1992, Sinkins et al. 1997). However, attempts to inject *Wolbachia* into *Anopheles* have so far been unsuccessful and there are precedents for breakdown of the linkage of transposons to other genes with which they had been "loaded" and for selection to favour the transposons alone.

Tight linkage of the gene driving system to the gene to be driven is essential if the combined system is to spread from a small "seeding" release and counter the effects of immigration. It is necessary to avoid even a limited rate of recombination of the driver and the factor to be driven because the same arguments about the danger of loss of anti-malaria immunity from incomplete control with bednets apply to genetic control which fails to go to completion.

REFERENCES


The French National Programme of Bovine Hypodermosis Eradication

Isabelle Amouroux

FNGDS, 149 rue de Bercy, 75012 Paris, France

INTRODUCTION

The National Federation of Sanitary Defence Organisations (FNGDS) is a professional organisation which brings together more than 95% cattle breeders within its departmental structures (GDS). Working closely with breeders within their local structures, the GDS maintains a high level of efficiency in communicating and informing farmers about sanitary programmes as well as rally them to participate in these programmes.

FNGDS has built a solid cooperation with the veterinary administration and private veterinarians in the fight against the most serious animal diseases. In the 1980s, new sanitary guidelines regarding export emphasised the necessity of fighting against the warble fly. As parasitic hypodermosis causes a major decrease in zootechnic performances, as well as is an important immuno depression, the GDS from different regions began the fight against it. Taking into account the fly biology, it was deemed necessary to establish a concerted fight in order to avoid recontamination in their regions as well as improve sanitary conditions.

In 1989, FNGDS proposed and implemented a national scheme for the eradication of hypodermis in collaboration with other professional and industrial organisations, scientists, veterinarians and the Ministry of Agriculture. In 1994, a law against the warble fly was enacted. This law required every region to fight against the fly beginning 1 July 1998. Before this deadline, all regions were encouraged to begin regional plans on a voluntary basis, which, nevertheless, had to be approved by a national committee.

Under the national scheme which was based on parasitic biology, each region had to build its own programme. It had to be in charge of the details of operation, e.g., regarding topography and the presence of Hypoderma lineatum Villers. Cooperation between animal health partners was greatly encouraged.

DEVELOPMENT CYCLE OF HYPODERMA

There are two species that infect cattle: Hypoderma bovis L. and H. lineatum. The adult stage is entirely a reproductive and dispersal phase. The infected cattle is dead within few days after larvae leave the body. The eggs hatch in about four days into larvae which immediately penetrate the host’s skin, often causing irritation and exudation. The larvae (L1) spend 8 months migrating through the inter-muscular connective tissue to the subcutaneous tissue of the back. They spend a significant period around the spinal cord (H. bovis) or in the oesophageal submucosa (H. lineatum). As the larvae reach the back of the infected animal, they attain the second stage: L2. Soon afterwards at the larger final stage, they reach the length of about 25 mm (L3). After 4
weeks the larvae emerge from the breathing hole and fall to the ground. The pupal stage lasts about a month. Then, the adults emerge, and the cycle goes on.

Warble flies appeared on the back of the cattle from March to August. Some observations have indicated that the highest sensitivity of visual controls can be obtained from 15 May to 15 June (Argente 1995).

A couple of hypoderma is able to parasite a hundred animals, 5 kilometres around, in two years. A collective fight is, therefore, necessary to eradicate hypodermosis.

ORGANISATIONAL PLAN

Administrative Organisation of the Plan

The territorial units to put the programme into practice are the administrative regions. To put the programme into practice, it must be agreed by more than 60% of breeders. Then each unit of cattle must be identified and registered in a list to be made accessible to the GDS. The GDS must also obtain information about the movement of each animal in a particular department.

At both the regional and national levels, the GDS established a plan describing what will be done for the next five years in each department of the region. This provisional plan regroups technical and financial provisions. Regional committees, formed by the GDS, which is the leader of these committees, veterinarians, the regional administration and professional organisations, meet twice per year. The GDS examines the result of the past campaigns, choose the orientation of the next campaign and validate it. The report sent to the national level is examined at two levels. First, the National Technical Commission examines programme results and compares the regional programme to national schemes from a technical point of view. This committee is composed of regional GDS, national veterinarians, scientists, other professional organisations and an administration representative. Second, the report is officially validated by the National Committee. This is the political committee, comprising all the professional organisations and the administrative representative. The GDS has to carry out the regional plan validated by the National Committee.

Each stage of the plan comprises systematic treatments, tactic treatments, introduced animal treatments, curative treatments and visual control. At each stage, the person in charge (breeder, veterinarian, etc.) will notify the GDS in writing the nature of the treatment that has been carried out. The GDS computerises all information. The organisation, at central and regional levels, is therefore provided with a reliable recording and reporting system. Two reports, representing regional results and plans, are sent in July and in September to the National Technical Committee to be examined.

Technical Organisation of the Plan

A region is usually divided into three areas. This programme is extended progressively. Usually three campaigns of systematic treatments are necessary in areas where the prevalence of infested cattle is 5%. Current methods to detect hypoderma infestation are the visual observation or palpation of the grubs when the larvae get to the back of the cattle, usually during spring. A cattle is declared infested when only one larva is seen on one animal.
As the prevalence of infested cattle becomes less than 5%, systematic treatments are no more obligatory. Tactical treatment however, continues. This treatment concerns each head of cattle.

An area is declared “cleansed” when the prevalence of infested cattle is below 5% for two consecutive years. Breeders can then benefit from the notice of “varron: zone assainie” under their bovine sanitary document (ASDA).

Treatment

First of all, the initial prevalence is calculated by visual control. Systematic treatments are preventive ones; they are conducted in autumn, in order to avoid the parasite incidence. The principle of systematic treatments is to treat each head of cattle in a determined area.

The breeders can treat only their young animals. Veterinarians have to be in charge of the treatment of all registered adult animals.

A list of products to be used in treatments is available and authorised in the national scheme. These products contain avermectine and milbemycine. The use of microdose ivermectin for the adults and for dairy cattle is recommended by the Technical National Committee. Only veterinarians can administer this type of treatment. The microdose ivermectin is 0.1 ml/animal, that is, corresponding to one hundredth of the approved dosage.

Treatments against the warble fly is done in the same time as the prophylactic visit. It is recommended that animals be treated as soon as possible and before 30 December, especially if they are infected by *H. lineatum*.

As soon as visual control indicates that the infested cattle rate is below 5%, tactical treatments are only required. These apply to cattle infested during the previous campaign and its neighbourhood 5 kilometres around and cattle where there is no information about the treatment of introduced animals.

Treatment for Introduced Animals

As the introduction of animals is the most likely way of re-infestation (two out of three heads) in a cleansed area, the national guideline dictates that each animal has to be treated except those coming from an officially cleansed area. The recommended treatment is microdose ivermectin, all year long, except when the animal is infected. In the latter case, as soon as larvae L2 or L3 are seen under the back of the animal, a curative treatment is conducted. A decree will soon oblige farmers to declare an infested animal in cleansed areas.

Control

The national guideline recognises a clinical infestation warble grub survey conducted in spring, as the common method.

With spring controls, it was possible to evaluate the efficiency of treatments conducted in autumn. It was imperative that treatments were effective because the management of treatments for the next campaign depended on their results.

In areas where systematic treatments were conducted, 20% of cattle had to be controlled. There are two types of visual controls:
• "Aleatory": Lots were drawn on cattle (Snedecor and Cochran 1971). Those picked were used to calculate prevalence of infestation.

• "Oriented": Cattle suspected of infestation were picked. This included cattle infested during the last spring, neighbouring cattle for which no proof of preventive treatment had been registered and cattle for which no information existed about introduced animal treatment, cattle owned by breeders who refused treatment, etc. Through oriented controls, breeders in the programme are instructed to look for warbles. This is very important to decrease the infestation.

"Aleatory" controls must be realised from 15 May to 15 June. However, depending on climatic variations, they can be extended from 1 May to 30 June.

An area is declared cleansed when the prevalence of infested cattle is below 5% for two consecutive years. To reach this certification of a "cleansed area", the number of cattle, determined on a statistical table, has to be controlled. Each following year, such controls are put into practice to validify the certification for the area.

At the same time, some visual controls are also conducted at the cattle market. In 1997, an information network between the regions of the GDS was created. This provided information to the GDS regarding the source of an infested animal. Further action by the GDS can then be taken.

As soon as an animal is considered infested by visual control (aleatory or oriented), a curative treatment is inspected by a veterinarian or in his presence.

RESULTS

Technical Aspects

Progression from region to region has been slow in some cases but the eradication plan is beginning to cover the entire national territory of 21 regions. Indeed, in the 1997/98 campaign, the five previous regions, which had originally opposed the plan, had agreed to it. For the first time in 1998, all French regions put into practice a regional programme of eradication.

Before the programme commenced, the prevalence of hypodermosis in French cattle had varied greatly with the regions, from 30% to 90%. While some regions achieved the 5% level in only two years, others took three or more years to do so.

Figure 1 shows the rates of regional infested cattle after the implementation of the eradication programme. There is still however, high infestation rates in some areas, as indicated by the National Technical Committee.

The actual situation is presented in Figure 2. Nine regions contain at least one cleansed area.

In the 1996/1997 campaign, 11 million animals were covered, corresponding to the ownership by 200,000 cattle breeders. During this period, nearly 3.5 million animals were treated in the systematic way while the other two-thirds were treated in a tactical way. That means that nearly 9 million animals were located in areas where the infestation rate was below 5%.

For the 1997/1998 campaign, 14 million animals in the ownership of 250,000 cattle breeders were involved.
Figure 1. Regional infestation herd rate.

Figure 2. Bovine hypodermosis eradication in France

Financial Aspects

The eradication programme for the 1996/1997 campaign cost about 60 million francs. Treatments cost the greatest amount. The cost was less than 5 francs on an average per animal, but this varied depending if an animal was in an area where systematic treatments were conducted (about 15 francs/animal), or in a cleansed area (about 2 francs/animal). Furthermore, costs varied even within regions.
Breeders and GDS bore more than 70% of the total costs. There was some financial support from national organisations such as the Ministry of Agriculture, which helped financially with visual controls. OFIVAL (Office National Interprofessionnel des Viandes, de l’Aviculture – National Interprofessional Meat, Livestock and Poultry Bureau) assisted by providing the breeders information while INTERBEV (L’Association Nationale Interprofessionnelle du Bœuf et des Viandes – French Meat and Livestock Association) assisted the breeders when an animal died following preventive or curative treatment. There was also some assistance at the European level and local level.

DISCUSSION

After nearly ten years of experience, we can establish the following points with regard to the management of the national eradication plan.

First of all, it is necessary to have solid collaboration between the different partners at the national and the local levels. Furthermore, to succeed in an eradication programme, there must be motivation among farmers from the beginning, as they have to be prepared to take action.

There were problems with ecologist breeders. A number of them did not want to treat their animals even with microdosed ivermectine which was, from FNGDS’ point of view, an “ecologist treatment”, considered acceptable by the administration, scientists, veterinarians and ecologist breeders. Using this method, breeders had to control each head of cattle every week during the entire emergence period of warbles. They had to extract larvae manually with oxygenated water. This method was time consuming, but was necessary because of the warble biology. Its implementation meant that there was no risk of recontamination of cattle which had already been treated. Furthermore, chemical products were not used.

During the previous ten years, we had to face some technical difficulties. One of the main problems was that no treatment for dairy cows was available. The recommended dose of ivermectine could not be used on dairy cattle and an interval of 42 days between treatment and slaughter was required to prevent the persistence of residues in milk and tissues. In fact, some studies have pointed out that microdosed ivermectine was highly efficient against the first larvae L1 of H. lineatum and H. bovis (Argente and Hillion 1984). Furthermore, other studies have shown that ivermectine residues in milk from lactating dairy cows which have been treated with microdoses cannot be detected by usual methods (Alvinerie et al. 1994). An official note published by Ministry of Agriculture fixed a milk LMR (Limit of Maximum Residue), which officially allowed the use of microdosed ivermectin, which does not have a AMM (licensed dosage).

The use of microdose ivermectin, however, has some major advantages: it is very low in cost, and causes minimal harm to both animal and environment. From the scientist’s point of view, such a treatment does not increase the risk for selecting drug resistant nematodes (Bauer 1994). Nevertheless, this treatment does not protect against side effects related to the destruction of larvae around the spine or the oesophagus and consequently the timing of treatment remains a priority.

However, it is crucial to use a “microdosage” and not the so called “minidose” (below).

The use of immunological diagnosis has to be recognised in the national guideline. It has already been put into practice in some areas. Indeed, visual controls are effective in a problem area, but as the area becomes cleansed, other methods should be
used. Epidemiological surveys are carried out using clinical detection for warbles, but with one inspection only about 50% of the real prevalence is expected. The use of immunological diagnosis on the ground has pointed out some major difficulties in serological interpretation (Petit 1994). In fact the two methods – visual control and serological diagnosis – do not measure the same indicators. The warble count reflects the total evolution of the parasite and the real risk of parasite pressure for the future. The immunological diagnostic indicates a contact between the parasite and the host which remains a proof of the presence of the disease in the herd within the previous year. Some studies have been realised, the effectiveness of a previous campaign to determine characteristics of this method: its sensitivity and its detectability. This method will be necessary to certificate cleared areas, corresponding to areas from which *Hypoderma* have been completely eliminated.

At the same time, an information system has been developed between GDS in order to warn each other about the possibility of infestation of cattle through an introduced animal which may have been infested. More generally, we have to develop epidemiological surveillance in order to be beware of infestation and to detect any residual infestation in a cleansed area.

**CONCLUSION**

In order to operate an eradication scheme successfully, public awareness and goodwill are essential. Farmers must be aware of the seriousness of problems and the benefits of eradication. That is why the implementation of the departmental structures with the GDS is an advantage. Indeed a lot of breeder meetings are organised each year and regularly, articles are published in national or local newspapers.

In the course of ten years, the plan is now at a strategic time of development. The entire French territory is covered and many regions have a very low infestation level. However, even if systematic treatment is implemented in most parts of France, the fight itself is far from ending. Protection of cleansed areas needs specific control measures that we have to develop: epidemiological surveillance and, of course, serological testing.

During the coming years, the different partners at the national and at the regional level will have to be determined and united to ensure that the programme is a national success.

We have to aim for the objective of the complete absence of the warble in the year 2000.

**REFERENCES**


Argente, G. 1995. Choix d’une périodicité pour les comptages de varrons; COST 811, European cooperation in the field of scientific and technical research, pp. 153.

Bauer, C. 1994. Does the use of microdosed ivermectin to control bovine hypodermosis increase the risk for selecting drug resistant nematodes?; COST 811, European cooperation in the field of scientific and technical research, pp. 145.


PART II.

APPLICATIONS OF THE AREA-WIDE CONCEPT TO NON-FRUIT FLIES

B) PLANT PESTS
Eradication of the Cotton Boll Weevil (*Anthomonus grandis*) in the United States – A Successful Multi-Regional Approach

*Gary L. Cunningham and William J. Grefenstette*

USDA-APHIS, 4700 River Road, Riverdale, Maryland 20737, United States

INTRODUCTION

The cotton boll weevil, *Anthomonus grandis* Boheman, is believed to have entered the United States of America (US) from Mexico and was first detected in South Texas in 1892. Since that time, the pest has spread throughout most of the nation's cotton-producing areas and has become the industry's number one nemesis (Figure 1).

![BW Infestation 1892–1922](image)

Figure 1. Boll weevil spread throughout most of the US within 30 years and led to major changes in agricultural practices.

More than US$13 billion in economic losses have occurred since its introduction, with recent annual expenditures of more than US$300 million for control costs alone. Although the weevil has been eradicated from over 4 million acres, its presence in non-programme areas continues to dictate production practices within the mid-south, Texas and Oklahoma.

INITIAL ERADICATION EFFORTS

The National Cotton Council, representing the US cotton industry, began efforts in 1958 to accelerate boll weevil research. As a result, a pilot eradication project began in portions of the mid-South in the early 1970s and led to successful eradication of the boll weevil in Virginia and North Carolina by 1980. Following grower-approved
referenda, the programme expanded in 1987 into Georgia, Florida, and Alabama in the southeast. Eradication efforts also began in the southwest US in Arizona and California. Both the southeast and southwest portions of the country, as well as a portion of northwest Mexico, are now weevil-free. Building upon these successes, the programme continues to expand rapidly throughout most of the remaining infested areas.

It is important to note that this programme has always had full support from the industry itself. This is not a United States Department of Agriculture (USDA)-mandated initiative that requests industry involvement. In fact, it is just the opposite. It is a grower-driven and grower-supported programme which coordinates implementation activities through USDA's Animal and Plant Health Inspection Service (APHIS) and a number of other federal and state agencies such as the Cooperative State Research, Education and Extension Service, the Farm Service Agency and State Departments of Agriculture. The programme's success continues to be contingent upon strong grower involvement and backing, as well as the industry's ability to organise itself in a united effort.

PROGRAMME COMPONENTS

The programme uses three principle techniques on a large, area-wide basis to eradicate the boll weevil. They include pheromone trapping, chemical treatment and cultural practices. These techniques have not changed significantly since the programme's inception – primarily because they continually prove to be the most effective, least expensive and most environmentally suitable.

The main function of the boll weevil pheromone trap is to detect weevil populations throughout the season. Before any eradication treatments are applied within the programme area, all cotton acreage is identified, mapped, and surveyed. The survey is done with pheromone traps, which are placed around all cotton fields at a density of approximately 1 trap per 50-75 acres. Traps are installed in mid-summer and serviced for several weeks prior to the onset of diapause. These surveys indicate large areas within the overall programme increment that are likely to support significant populations of overwintered weevils each season. The traps are also used to help monitor treatment efficacy. In subsequent years, during active eradication, traps are placed in the spring at a density of 1 trap per 1-5 acres, and they are monitored for the entire season.

Pesticide treatments, usually malathion at ultra-low volumes (10-16 ounces per acre; 0.75-1.2 lb. active ingredient per acre), are carefully applied in response to trapping results, and only infested fields are treated. In those areas where aerial application is not practical, such as sensitive areas near dwellings or along streams and ponds, high-clearance ground equipment or truck-mounted mistblowers provide for a more precise placement of pesticides. In addition, an extensive environmental monitoring plan is implemented to comply with federal and state pesticide laws and to protect human health along with threatened and endangered plant and animal species.

During the first full season of the programme, after the initial series of fall treatments, the average number and frequency of insecticide applications vary across the Cotton Belt. In most infested areas, 6-8 applications generally will be required during the growing season. In a few heavily infested fields, as many as 15 treatments may be required. During the second full season, the number of fields and the number of chemical treatments applied are usually reduced by 40 to 60 percent. The third season is used to isolate and eliminate lingering weevil populations.
Growers are encouraged to follow good cultural practices that limit early- and late-season food supply for the weevil. These practices include uniform delayed planting, use of short-season cotton varieties, early harvesting and destroying stalks immediately after harvest. Other cultural practices which have been identified as helpful include keeping field borders clear and accessible, and not planting cotton next to environmentally sensitive areas, such as schoolyards, churches, and bodies of water.

The eradication phase is considered complete when spring-trapping indicates 99 percent of the programme acreage is free of infestation. The final phase confirmation concentrates on the remaining infested acres and lasts until boll weevils are no longer detected in traps. Post-eradication activities continue until the risk of re-infestation becomes insignificant and include annual field mapping, trapping, and response to any weevils captured. In most programme areas, boll weevil populations will be eliminated in an average of two years, with an additional year of moderate-density trapping to confirm eradication.

ORGANISATIONAL STRUCTURE AND FUNDING

The continued success of the boll weevil eradication programme is due in large part to an organisational structure which places the effected commodity group (cotton growers) in the central leadership role. Each state has a Boll Weevil Eradication Foundation, consisting of local growers and a representative of the State Department of Agriculture to help guide activities and assist in policy decisions which may arise periodically. Before a state programme is started, a referendum must be passed (usually by two-third majority) which then requires 100 percent participation by all cotton growers in the proposed zone.

Federal assistance, which until recently provided up to 30 percent of the programme's funding, is no longer guaranteed. The US Department of Agriculture's Farm Services Agency, however, initiated a loan programme in 1997. Loans are made to officially recognised boll weevil eradication foundations to help make the programme more affordable. These loans, which totalled US$40 million in 1997, usually involve modest interest rates and a term of seven or eight years. This financing helps to defray the high cost of starting a programme, spreads the cost over a few more years, and makes the growers' annual programme cost more acceptable. Depending on the particular programme area, state funds may be used to offset grower assessments, in some instances by more than 50 percent. The APHIS federal funds to the belt-wide programme are down significantly from previous years, providing only 13 percent of overall costs in 1998.

CURRENT PROGRAMME STATUS

Within the 13 million acres of cotton grown nation-wide, the boll weevil has been eradicated from more than four million acres, spread across eight states in the southeast and southwest portions of the country (Figure 2). Approximately two million acres are currently in active eradication in the mid-south and Texas. Another 700,000 acres within four new zones in New Mexico, Oklahoma, Mississippi, and Tennessee will start with a series of diapause treatments this fall. Other zones, especially in Texas, Louisiana, and Mississippi, are preparing to hold referenda and could begin as early as the fall of 1999.
Boll Weevil Eradication Status

(1998 Season)

Figure 2. Current status of the boll weevil eradication programme in the US.

BENEFITS

Recent farm legislation and the resulting decline in federal price supports make it imperative that growers compete successfully in international markets. For this to occur, there must be significant increases in yield and/or substantial reduction in production costs. Boll weevil eradication accomplishes the latter and has also dramatically increased yields in many areas. The National Cotton Council (Anonymous 1994) conservatively projects a 12:1 benefit-to-cost ratio for nation-wide eradication. Agricultural economists in Louisiana recently projected a benefit-to-cost ratio of 40:1 for boll weevil eradication in their state. These ratios are derived, in part, from eliminating the dollar value of yield lost to weevils and the resultant benefits pumped into the local economy. New jobs in ginning, warehousing, seed crushing and textile manufacturing have occurred as a direct result of eradication. In Georgia alone (Haney et al. 1996), insecticide applications have decreased more than 60 percent, pest management costs are 30 percent lower and overall crop damage is down by nearly 70 percent. Farm land values have also increased.

Environmentally, integrated pest management strategies for controlling secondary pests have a much better chance of succeeding in the absence of the boll weevil. And just as important, eradication provides a cleaner environment as a result of the 40- to 90-percent reduction in the amount of pesticides used each year on cotton.

FUTURE PROSPECTS

These are exciting times for the boll weevil eradication programme. Momentum is building within the industry to hasten the weevil's demise, in part, because growers now realise that they can no longer compete effectively with those who have rid themselves of the pest. In the southeast US alone, where the weevil has been eliminated, there has been a 3.8-fold increase in cotton acreage during the past ten years, while
other areas such as the mid-south and Texas have barely maintained their acreage. Increased use of *Bacillus thuringiensis* (Bt) cotton has added to growers' awareness of boll weevil pressure. With Bt cotton, less insecticides are now needed to control lepidopterous pests. As a result, boll weevil populations which used to be suppressed indirectly by worm treatments, are now free to increase. Areas which were not previously aware of weevil problems are now realising the need to take action.

Numerous challenges remain. As the programme moves northward where weevil populations are less intense, there will be likely less interest by affected growers to finance an eradication effort because their losses to the pest are less severe. But an unusually warm winter throughout most of the Cotton Belt in 1997-1998 greatly increased the weevils' ability to overwinter. This could result in much higher than normal populations during the 1998 season. Increased urbanisation of farmland and the presence of sensitive areas such as churches, schools, and hospitals, as well as organic cotton fields where no pesticides can be sprayed, require the consideration of alternative techniques such as bait tubes, biological control with *Catolaccus grandis* Burks, and cotton-free buffer zones. As the weevil is eradicated along the US border, cooperative efforts with Mexico for suppression or eradication on their side will have to be maintained. Such is already the case in the northern portions of the Mexican states of Baja California and Sonora.

Although not insurmountable, these situations will undoubtedly challenge programme leaders and cause some delay in programme implementation. The industry, however, maintains its strong commitment and support for boll weevil eradication, and remains undaunted in its determination to rid the country of this pest within the next 5-10 years.

**REFERENCES**


INTRODUCTION

The western corn rootworm, *Diabrotica virgifera virgifera* LeConte, northern corn rootworm, *D. barberi* Smith and Lawrence, and Mexican corn rootworm, *D. virgifera zeae* Krysan and Smith are among the most economically and environmentally important pests of United States maize (*Zea mays* L.) production systems (Metcalf 1986). Annually, 8 to 10 million hectares of maize are treated with soil applied insecticides to protect the crop from larval feeding damage. Crop rotation, however, is also widely used to minimise the need for soil insecticide applications. Insecticides for adult rootworm management are also frequently used.

Numerous problems are currently associated with corn rootworm management approaches. Soil insecticides are normally used to protect maize roots from larval feeding damage. However, they are ineffective in controlling the management of corn rootworm populations (Gray et al. 1992, Sutter et al. 1991). It is not uncommon for large numbers of rootworms to develop within treated fields. Thus, when maize is grown in the same field year after year (continuous cropping), soil insecticide applications must be used to protect the plant. These applications are generally made without knowledge (prophylactic) of the rootworm population levels within the field due to the difficulty of sampling for immature life stages.

Crop rotation, where maize is planted every other year following soybean (*Glycine max* (L.) Merr.), is used throughout the United States Corn Belt as a primary rootworm management tool. In the southwestern United States, maize is also rotated with grain sorghum (*Sorghum bicolor* (L.) Moench). Rootworm species have altered their behaviour to adapt to these rotational schemes. Portions of northern and western corn rootworm populations throughout the Corn Belt have developed extended diapause traits which allow eggs to overwinter for more than one year, thus allowing larvae to hatch when maize is again planted (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986). A significant portion of the western corn rootworm population in the midwestern United States (east central Illinois, northern Indiana, southern Michigan, and western Ohio) has developed an affinity for ovipositing eggs into soybean (Krysan et al. 1986).
Western corn rootworm resistance to chlorinated hydrocarbon insecticides has been extensively documented (Ball and Weekman 1962). Recently, two distinct populations of western corn rootworms in Nebraska were found to be resistant to carbaryl and methyl parathion which are commonly used for adult control (Meinke et al. 1998). Although the occurrence of resistance has not spread outside of these areas, the potential for increased tolerance of western corn rootworm populations to carbamate and organophosphate insecticides across the region does exist.

In response to many of the management problems discussed above, scientists with the USDA Agricultural Research Service and cooperating north central United States universities developed a semiochemical insecticide-bait targeted at adult corn rootworms (Sutter and Hesler 1993). The bait, composed of cucurbitacins, a minute amount of carbaryl, and a non-toxic edible carrier, can be applied by conventional aerial or ground sprayers (Hoffmann et al. 1996, Chandler and Sutter 1997, Chandler 1998). The bait adheres to plant surfaces and stimulates rootworm adult feeding, resulting in high levels of mortality and little impact on secondary pests or beneficial arthropods. The bait is applied when females predominate in the field and before significant oviposition begins. By targeting females at this critical developmental stage, egg laying can be reduced and thus, economic larval infestations can be avoided in the following growing season. Unlike soil insecticides, where maize root protection is the primary goal, this control tactic manages rootworm populations.

The development of this bait along with improved rootworm monitoring techniques and better understanding of rootworm biology/ecology, forms the basis for the corn rootworm area-wide management programme. Management of rootworm populations using the bait concept is best accomplished when conducted over a large area. Thus, a regional or area-wide approach may effectively reduce rootworm populations, resulting in significant economic savings to growers and improved environmental stewardship through the reduction of insecticide use throughout maize production areas. The information presented discusses the development of the corn rootworm area-wide programme, the initiation of the operational component of the programme, and the results of the first year of semiochemical-bait applications.

MATERIALS AND METHODS

Programme Development

In 1995, the Corn Rootworm Area-Wide Management Ad Hoc Committee was formed to guide development and implementation of the programme. The Committee is currently composed of representatives from several USDA agencies (Agricultural Research Service (ARS), Cooperative States Research, Education, and Extension Service and the Economic Research Service) and individuals from cooperating universities. The Committee developed the following mission statement as a guide to the overall programme, this being the successful establishment and implementation of an area-wide demonstration programme that:

- is the result of a partnership of growers, private consultants, applicators and suppliers, research and extension personnel, and local, state and federal agencies who have a stake in the development and adoption of improved crop management technologies,
clearly demonstrates advantages of enhanced grower profits, reduced risks, enhanced environmental compatibility, and superiority of Integrated Pest Management (IPM) approaches compared to current pest control approaches.

The goals of the programme are:

- to demonstrate an area-wide IPM concept for the control of corn rootworm and other pests of maize such that voluntary adoption will occur throughout all maize growing regions,
- to develop a partnership of federal, state, local, and private interests which will be involved in the programme from conception to adoption.

The mission and goals of the programme were first presented publicly at a stakeholders' meeting held in St. Louis, Missouri in the fall of 1995. This meeting included both supporters and critics of the concept resulting in open and frank discussion of the merits of a corn rootworm area-wide management programme. The group recommended that evaluation of the area-wide concept at multiple locations throughout the United States maize production area was needed, and that expansion of the programme should begin in 1996. It was immediately recognised that the extensive size of the maize production area in the United States presented numerous differences in environmental conditions and resulting crop and pest management tactics. Therefore, the multiple location demonstration concept was devised to encompass as many of the major maize production differences encountered across the country as possible.

The Ad Hoc Committee recommended that the programme be implemented in three phases: 1) Phase I - evaluation and selection of study sites, development of background information, and education – 1996; 2) Phase II - full scale implementation of the programme – 1997-1999; and 3) Phase III - technology transfer to growers and interested parties – 2000.

The Agricultural Research Service provided approximately $550,000 for Phase I funding in the fiscal year 1996. Funding for Phase II was approximately US$1.6 million in 1997 and is targeted at approximately US$1.5 million for 1998. Funds were distributed to cooperators using established Agricultural Research Service intra-agency fund transfers and specific cooperative agreements with cooperating universities.

Site Locations

Five sites across the United States are currently being used for the area-wide management study/demonstration. Each site has a companion “normal” maize production area for comparison of area-wide vs. conventional management practices. The sites are:

Cooperator Site A

This site is located in eastern Iroquois Co., Illinois, and western Benton Co. and Newton Co., Indiana (41km² in size). This programme targets western corn rootworm within a corn/soybean rotation system and is located in the heart of the region experiencing significant western corn rootworm behavioural changes resulting in oviposition in soybean. Purdue University manages the site in cooperation with the University of Illinois.
Cooperator Site B

This site is located in Clinton Co., Iowa (41 km² in size). This area-wide programme targets western and northern corn rootworms in a primarily continuous maize production area. Some soybean is grown in rotation. Iowa State University manages the site. Staff from the University of Minnesota, South Dakota State University, and the Agricultural Research Service Corn Insects Laboratory in Ames, Iowa cooperate on various aspects of the research activities.

Cooperator Site C

The site is located in Republic Co., Kansas (41 km² in size) near the town of Scandia. This programme targets western corn rootworm in a furrow irrigated continuous maize production area. Kansas State University manages the activities within the site.

ARS Site A

This site is located in Bell Co., Texas (21 km² in size) near the town of Little River. This management area targets Mexican corn rootworms in a maize/grain sorghum production system. The Agricultural Research Service Area-wide Pest Management Research Unit in College Station, Texas manages the site in cooperation with the Texas Agricultural Extension Service and Texas A&M University.

ARS Site B

This study area is located in Brookings Co., South Dakota (41 km² in size) near the town of Aurora. This management area targets western and northern corn rootworm in a maize/soybean rotation production area. Some continuous maize is grown using a centre pivot irrigation system. The Agricultural Research Service Northern Grain Insects Research Laboratory in Brookings, South Dakota, manages the site in cooperation with South Dakota State University.

General Conduct of the Programme

Background information was gathered at each study site during 1996 and the first few months of 1997. That information was used to predict the severity of corn rootworm populations and to determine the need for soil insecticide applications to reduce larval feeding damage during the first growing season (Phase II) of the programme. Soil insecticide applications were made where necessary to assist maize production before full fledged corn rootworm population management was introduced at the sites.

Two methods were selected to monitor corn rootworm populations during the implementation phase of the programme. Pherocon® AM (yellow sticky traps) traps were selected as the primary means for tracking insect populations and initiating semiochemical insecticide-bait applications in maize at Cooperator Sites B and C and ARS Site B. Adult counts from maize plants were used to trigger bait applications to maize at Cooperator Site A and ARS Site A. Pherocon AM traps were used to initiate bait applications in soybean at Cooperator Site A. Pherocon AM traps were monitored at all sites on at least a weekly basis. Cumulative counts of 5 to 6 beetles/trap/day for 7
consecutive days were used as a treatment threshold in maize, while counts of 2 beetles/trap/day for 7 consecutive days were used to trigger applications in soybean. Additionally, these applications were made only when gravid females were present. Maize plant counts in Illinois and Indiana triggered bait applications when counts of 0.5 beetles/plant or more were observed and when gravid females were present. Re-application of bait was made as necessary if corn rootworm populations reached treatment thresholds.

Adult emergence cages were also placed in several fields within the centre most area (core) of each area-wide management site to determine the timing and pattern of male/female emergence. These data are being used to assist decisions in bait applications and to help ground truth predictive models.

Root ratings using the Iowa 1-6 scale (Hills and Peters 1971) will be conducted in 1998-2000 at each site to assess the success or failure of the previous years semiochemical-bait applications. Ratings will be conducted in a sampling of core and companion area fields.

Secondary arthropod pests and beneficial insects will be monitored weekly at each site using visual observations, trapping methods, sweep nets, etc. Secondary pest outbreaks will be handled on a case by case basis and management will be based upon the recommendation of the site managers and cooperating crop consultants.

Each year, all sites will develop GIS/GPS maps of each field within the area-wide and companion sites. These maps will assist overall analysis of the programme and provide useful information on insect movement and population dynamics, crop phenology and production, soil types, etc. GPS will be used by aerial applicators to locate fields for treatment.

**Semiochemical-bait Applications**

Corn rootworm adults will initially be managed using the semiochemical insecticide-bait SLAM® (MicroFlo Co., Lakeland, FL). Bait applications will be made using either high clearance ground sprayers or aircraft. SLAM will be applied at 230 to 561 gm of product/ha in 9 to 19 litres of water per ha. An additive will be used to improve rain-fastness of the bait on plant leaves. Rates selected will be dependent upon corn rootworm population pressure. Finished product droplet size should average 600 microns in diameter.

**Economic Assessment**

Agricultural economists at Purdue University will determine the impacts of the corn rootworm area-wide management programme on farm profits and will develop spreadsheet budget models to analyse programme and non-programme farms for each site. Additionally, a study to determine the implications of area-wide management on input supply firms (agricultural chemicals and associated pest control/ consulting services) will be conducted.

**Sociological Assessment**

Rural sociologists at Iowa State University will conduct studies to assess sociological barriers and opportunities for education, understanding, and successful promotion of corn rootworm area-wide management at all study sites.
Insecticide Resistance Management

Entomologists at the University of Nebraska in cooperation with the Agricultural Research Service Northern Grain Insects Research Laboratory, will monitor corn rootworm susceptibility to carbaryl in all area-wide management study sites. Development and validation of carbaryl diagnostic concentrations will occur. Factors responsible for the development of insecticide resistance and the biochemical and molecular mechanisms of resistance in existing resistant populations will also be investigated.

RESULTS AND DISCUSSION

Cooperator Site A

The Illinois/Indiana site enlisted the partnership of 45 growers and approximately 4,600 ha of corn (94 fields) and soybean (73 fields). An additional 14 maize and 11 soybean fields (a total of approximately 700 ha) comprised the untreated companion area. Western corn rootworm sampling began on 21 July and ended on 3 September.

Western corn rootworm beetle populations were extremely high in the study site and companion area. First applications of SLAM were made on 28 July to two maize fields. In the 3 days following, 63 maize fields and 5 soybean fields were treated. By 22 August, 39, 50, and 5 maize fields, and 40, 21, and 6 soybean fields had been treated with SLAM once, twice, or three times, respectively. Several fields were sprayed after 22 August with Sevin XLR Plus due to economic considerations.

Final statistics showed that 75 fields were treated once with SLAM, 65 twice, and 11 three times. Twenty-eight fields were treated with Sevin XLR Plus. Initial efficacy from the SLAM applications was good. However, a continuous wave of western corn rootworms that inundated the area-wide site resulted in the need for numerous additional applications. Despite the large numbers of corn rootworms encountered, it is reasonable to expect that there will be fewer larvae and fewer beetles to manage in 1998.

Cooperator Site B

In 1997, the Iowa area-wide management site was composed of 118 maize fields (approximately 2500 ha) of which 90% were considered continuous growing of maize. Forty growers participated in the activity during the year.

Western corn rootworm beetle emergence began on 12 July, about 10 days later than normal due to the cooler weather in May and June. Beetle populations reached treatment threshold beginning 28-29 July. SLAM applications began on 5 August. About 10 days of residual activity was obtained with the SLAM treatments. Continued beetle emergence brought beetle numbers to the re-treatment level by 22 August.

Beetle populations were very high in nearly all the monitored fields. A total of 2270 ha (about 93% of the total) were sprayed with SLAM once. An additional 1223 ha of maize was re-treated. Beetle kill following applications was effective.
**Cooperator Site C**

Thirty-six growers were partners with the area-wide management site located near Scandia, Kansas. These growers had 98 fields of maize encompassing approximately 1720 ha in total size. An additional 11 growers provided maize fields (23 fields with a total size of 529 ha) in the control area.

First western corn rootworm beetle emergence was observed on 4 July. The last adults were collected from emergence cages on 4 August within the management area. Peak emergence occurred from 10-21 July, with SLAM applications occurring during this time.

Forty-four of the 98 fields (1179 ha or 68.5% of the total maize hectares) required a SLAM application. An additional 316 ha required a second treatment due to rootworm numbers re-approaching threshold or because of product (SLAM) problems (unreliability or droplet size/placement problems). After adjusting some of the initial application problems, SLAM appeared to provide excellent (> 95%) control in all treated fields.

**ARS Site A**

The 1997 activities at this site were a continuation of full-scale area-wide management initiated at this location in 1996. A total of 8 growers participated in this study. A total of 791 ha of maize and 334 ha of grain sorghum was included within the area-wide site and an additional 4 maize fields were used as controls.

Mexican corn rootworms first emerged in mid-May with 90% emergence complete by the third week of June. SLAM applications were initiated on 24 June and were completed by 26 June. Root ratings taken in 1997 from fields treated with SLAM in 1996 indicated there was significantly less root damage in those fields compared to control fields and thus fewer beetles emerging (95% reduction in the SLAM treated fields compared to the control fields) throughout the area.

A total of 209 ha of maize was treated with SLAM in 1997. No fields required re-treatment. SLAM applications significantly reduced (>95% control) Mexican corn rootworm adult numbers and appeared effective in managing the population.

**ARS Site B**

In 1997, 20 growers had 56 maize fields (1383 ha) within the area-wide management site east of Brookings, South Dakota. Continuous maize was grown in 12 fields (316 ha). Five continuous maize production fields outside the area were used as untreated controls.

Northern and western corn rootworm emergence began during the second week of July. Peak emergence occurred during the period from 25 July through 8 August. SLAM applications were initiated the week of 4 August and continued through the first week of September. No re-treatments were required.

Eighteen maize fields (535 ha) were treated with SLAM during the season. Seven continuous (233 ha), 10 first year (238 ha), and 1 mixed (both first and continuous corn 65 ha) field were treated. In all cases, SLAM applications substantially reduced corn rootworm adult numbers below treatment thresholds.
GENERAL DISCUSSION AND CONCLUSIONS

The initial results from the first year of Phase II corn rootworm area-wide management were encouraging. Corn rootworm beetle numbers were reduced at all study sites. Initial carbaryl resistance surveys did not detect any development of increased levels of beetle tolerance to the insecticide-bait. Thus, the bait should remain a viable management tool for the foreseeable future. Economic and sociological surveys are being conducted to determine the fiscal effectiveness and general attitude towards conducting corn rootworm management across the Corn Belt. It is too early to tell how successful 1997 was in managing corn rootworm populations. Likewise, it is also too early to predict when, and if, adoption of this regionalised approach to rootworm management will occur.

Cooperation among all participants has been outstanding. The management structure of each site has evolved and is positioned to handle the transfer of the area-wide technology if further assessment indicates this to be a feasible approach. We recognise that area-wide management of corn rootworms may not work well in every maize production area throughout the United States. However, the data we expect to gather in 1998 and beyond will provide us with much needed information to more accurately structure area-wide programmes to the needs of local clientele and to determine feasibility of expanding the approach.

ACKNOWLEDGEMENTS

The corn rootworm area-wide management programme would not have been possible without the immense support provided by numerous individuals. Although we cannot list all cooperators as authors, we wish to gratefully acknowledge the following individuals for their participation, in and support of, the corn rootworm area-wide management programme: Larry Bledsoe, Wayne Buhler, Larry Buschman, Jesse Cocke, Stan Daberkow, Jerry DeWitt, Ric Dunkle, Robert Faust, Billy Fuller, Corey Gerber, Mike Gray, Deb Hartman, Randy Higgins, Clint Hoffmann, Denise Hovland, Gretchen Jones, Buddy Kirk, Les Lewis, Scott Lingren, Mickey McGuire, Marshall Martin, Lance Meinke, Tim Nowatski, Eldon Ortman, Ken Ostlie, Steve Padgitt, Randy Pingell, Walt Riedell, Rich Roehrdanz, Mike Scharf, Roxanne Shufran, Blair Siegfried, Phil Sloderbeck, Kevin Steffey, Harry Stockdale, Jeff Whitworth, Dave Woodson, Robert Wright, and Kun Yan Zhu. Additionally, the efforts of our administrative support staff at each cooperating institution, industry partners (BASF Inc., MicroFlo Co., Trece Inc.) and numerous local agricultural businesses are much appreciated. Finally, the programme could not have gone forward without the cooperation and enthusiasm of the many growers who actively embraced the concept and who have supported the activities of the many research groups involved.

REFERENCES


Meinke, L.J., B.D. Siegfried, R.J. Wright and L.D. Chandler. 1998. Adult susceptibility of Nebraska western corn rootworm (Coleoptera: Chrysomelidae) populations to selected insecticides. J. Econ. Entomol. 91: 594-600.


Area-Wide Pest Management of Locusts and Grasshoppers: The Striking Similarities of Problems and Solutions in Africa and The United States

Jeffrey A. Lockwood

Entomology Section, Department of Renewable Resources, University of Wyoming, Laramie, Wyoming, USA

INTRODUCTION: OPENING A DIALOGUE

Grasshoppers and locusts are among the most devastating pests of human agriculture. These insects cause serious damage to crops and forage on every arable continent, and their depredations have become the basis for legends, myths, and (in recent times) complex political and economic programmes. No pest problem spans such immense areas, with up to 8 million ha treated for rangeland grasshoppers during outbreaks in the US and 16 million km$^2$ prone to outbreaks of the Desert locust, *Schistocerca gregaria* Forskål, alone. The traditional management approach has involved extensive, regionalised control programmes, but recent trends suggest a decentralised future for grasshopper and locust management. Hence, we have a dynamic situation that presents the opportunity for a comparative analysis of the costs and benefits of an area-wide approach to pest management at different scales.

As political, cultural, and communication barriers between scientists dissolve, the possibility of learning from one another's experiences (both failures and successes) promises to dramatically accelerate the rate of innovation, progress and discovery in pest management. For example, the recent advances in Reduced Agent-Area Treatments (RAAT, in which insecticide is applied to swaths, separated by untreated swaths or buffers) for management of rangeland grasshoppers in the US (Lockwood and Schell 1997) are based on the adaptation of tactics developed by African, Australian, Asian, and European scientists (Rachadi and Foucart 1996, Musuna and Mugisha 1997, Scherer and Célestin 1997, Wilps and Diop 1997, Launois and Rachadi 1997).

The key to successful adaptation of management methods must begin with intellectual modesty and nationalistic humility so that the insights of non-scientists and experts from outside one's country are given respect and serious consideration. It is subsequently necessary to recognise the essential similarities and differences between land use systems and understand the political and socioeconomic contexts in which strategies have developed. In the light of these considerations, I shall briefly review the comparative ecologies, economics, and politics of area-wide locust and grasshopper management in Africa and the US and derive a set of common concerns and approaches to resolving the emergent issues.

I cannot claim to fully understand the complexities of locust management in Africa, as it has taken more than a decade for me to gain insight regarding the biological and cultural subtleties of grasshopper management on rangeland in the US. However, I am confident that we have a great deal to gain from an open dialogue, and this paper is an attempt to open such a discussion with apologies for what are sure to be simplifications and errors of interpretation in summarising an enormously complicated and sophisticated system of locust management.
COMPARATIVE ECOLOGY: GRASSHOPPERS VS. LOCUSTS

Similarities: A Common Set of Essential Characteristics

For the purposes of the analysis, I shall use the term “grasshoppers” to refer to rangeland acridids in the US (understanding that this definition in no way reflects the tremendous diversity of temperate and tropical grasshoppers and their attendant management systems) and the term “locusts” to refer to locusts in Africa (and primarily the Desert locust, *S. gregaria*, which remains the dominant pest species but represents only a portion of the remarkable range of locusts found around the world). In essence, locusts are simply those species of grasshoppers that exhibit behavioural and physiological “phase changes” associated with migration or under crowded conditions. This capacity to exhibit a gregarious phase is a continuous, rather than discrete, biological characteristic with some species being more “locust-like” than others. In this context, grasshoppers and locusts have three critical similarities that allow a basis for common concerns and approaches to pest management. First, both are in the Family Acrididae, and thereby share a number of fundamental physiological, behavioural, and ecological similarities, including: hemimetabolous development (eggs, nymphs, and adults), egg pods which are usually buried in the soil, susceptibility to similar pathogens, efficient water conservation, capacity for rapid population growth, etc. (Uvarov 1966, 1977).

Second, all pest species of acridids are native to the habitats in which they occur. Although movements may be extensive, there are no exotic pest species in Africa or the US. Hence, these organisms are not, by definition, targets of classical biological control programmes (the use of exotic agents to control co-evolved, exotic pests). Moreover, given that these species have evolved within the ecosystems where they occur, eradication is an ecologically risky and economically untenable management strategy. Considerable evidence suggests that the extirpation or chronic suppression of native species from core areas of their range, particularly those that appear to be so deeply integrated into immense, native ecosystems, is ill-advised (Lockwood 1993a, b).

Third, the outbreak dynamics of grasshoppers and locusts are the manifestation of natural processes in which the organisms exploit ephemeral resources that arise and disappear as a function of erratic weather conditions. These opportunistic resource trackers (Kemp 1992), may have the frequency, duration or scale of their population dynamics modified by human activities (Lockwood et al. 1983), but the essential capacity for catastrophic outbreaks is an evolved strategy to exploit unpredictably abundant resources. This life history strategy allows locust and grasshopper outbreaks to encompass immense spatial scales, which necessitates an “area-wide” approach to their detection and management.

Differences: The Necessity for Careful Extrapolation

Although locusts and grasshoppers have essential ecological similarities, there are a number of important differences that require careful adaptation of management approaches from one system to the other (El-Gammal et al. 1995). These differences limit the direct extrapolation of methods, but with thoughtful modifications, some approaches may be even more viable in the novel setting than in the original context. In essence, there are five factors that must be considered as we compare and exchange management tactics and philosophies between Africa and the US.
First, grasshopper species are typically univoltine (one generation per year), while locusts are almost invariably multivoltine, at least during the development of outbreaks (Uvarov 1966, 1977, Pedgley 1981). Hence, locusts have an intrinsically greater capacity for population increase on an annual basis, so the optimal mortality of a locust control programme is nearly 100%, and a lag in our response to a growing infestation has serious consequences. Conversely, 80-90% control is the goal of a grasshopper control programme, and the timing of intervention is much more critical, as there is typically only a 2 to 4 week window during which treatments are efficacious in any given year (DeBrey et al. 1993).

Second, grasshopper outbreaks are often composed of many species, with 2 to 5 species typically comprising the majority of the infestation and another 5 to 15 species “coat-tailing” as predators are swamped by the enormous population densities (Joern and Gaines 1990, Lockwood 1997). Thus, management strategies should consider a wide range of feeding, reproductive, and related behaviours. Consequently, target-specific approaches are rarely employed (e.g., the use of bran bait formulations has been largely abandoned, as many common pests species do not consume baits, and viral biological control agents have been dismissed as being too narrow in their host range to warrant the cost of development (Onsager et al. 1990-1993). Locust outbreaks are usually comprised of a single species, so the opportunity for host-specific cultural and biological control approaches is greatly enhanced (Lomer and Prior 1992).

Third, during an outbreak, grasshoppers are usually more sedentary than locusts. At high densities, locust nymphs travel long distances in tightly cohesive bands (a phenomenon virtually unknown in the grasshoppers). Although a few grasshopper species can exhibit swarming behaviour, this is an unusual behaviour (Pfadt 1988). The greater mobility of locusts has profound management implications. For example, much larger areas must be incorporated into a locust control programme, and tracking the movement of swarms becomes a critical element of a campaign. Indeed, their movements may necessitate the repeated treatment of a re-invaded area. However, there are also logistical advantages of a mobile pest. Strips of insecticides spaced at >1 km can serve as barriers during control programmes for nymphal bands, while effective control of grasshopper populations requires strips of insecticide at 8 to 70 m intervals (Rachadi and Foucart 1996, Lockwood and Schell 1997).

Fourth, in an area-wide context, grasshoppers are pests of rangelands (and hence, animal production) in the US. Although crop damage can occur when rangeland infestations move into agricultural lands, the primary focus of large-scale survey and treatment programmes has been the native grass- and shrublands of the western states (Hewitt and Onsager 1983, Schell and Lockwood 1997a,b). Locust outbreaks may also originate in uncultivated lands, but the singular focus of control is the prevention of crop damage as swarms migrate into agricultural areas (Pedgley 1981). Hence, concerns for residues on food crops are particularly relevant in locust control programmes.

Fifth, the management of grasshoppers in the US has primarily been a matter of economic concern. That is, the decision support systems and infrastructure of management (Berry et al. 1994, Hastings et al. 1996) are concentrated on the question of economic thresholds, benefit:cost ratios and similar financial measures of a programme’s success. Recently however, the National Grasshopper Management Board (1995, 1998) has taken the more expansive position that the goal of grasshopper management is to keep good stewards on the land. This re-perception of purpose has brought grasshopper management much closer to the philosophy of locust management. In Africa, the fundamental concern is food security, not economic efficacy, and keeping productive and sustainable agriculturalists on the land is a critical aspect of food
security. This convergence of motivations serves as a common point of departure for discussions of how US and African acridologists and pest managers may learn from one another as the parameters of area-wide programmes are changing.

MANAGEMENT ISSUES: A CONVERGENCE OF FUTURES

In developing a comparative analysis of area-wide grasshopper and locust control programmes, it is valuable to consider the following geopolitical premise: the relationships between states and the federal government in the US are remarkably similar to the relationships between nations and international agencies in Africa. In the US, the primary responsibility and source of funding for grasshopper control have been with the US Department of Agriculture's Animal and Plant Health Inspection Service (USDA-APHIS). The states have not had to coordinate, fund, or conduct surveys, environmental documentation, area-wide control programmes, or training and research efforts associated with grasshopper management. Similarly, the United Nations' Food and Agriculture Organization (UN-FAO) has been the primary source of logistical resources and the coordinating body for utilisation of bilateral and multilateral funds for control operations. The other key component of a sound comparative analysis is the common vision of decentralisation, which appears to be a dominant trend for both APHIS and FAO (Husnick 1995, FAO 1998). In turn, decentralisation is a function of several, interacting factors which include declining funding, which may, itself, reflect the general paucity of evidence that large-scale pest management has been effective in reducing the severity, frequency or duration of grasshopper or locust outbreaks in the US and Africa. Indeed, some evidence suggests that large-scale, long-term use of broad-spectrum insecticides may exacerbate grasshopper population dynamics (Lockwood et al. 1988). Thus, the combination of the geopolitical conditions and the localisation of programmes underlies the converging, fundamental pest management issues defining the future of grasshopper and locust control, which include: the scale of the management programmes, the purpose of intervention, the sources of funding for control, the timing of the response to an outbreak and the constraints on the type of programme that emerges.

Scale of Management: Regional vs. Local

The traditional scale of grasshopper and locust pest management has been an extreme version of the area-wide concept. This approach has been perhaps the single most important factor in defining the other elements of the pest management programmes. When intervention occurs over millions of hectares, the cost, timing, and constraints are essentially dictated. However, in recent years, there appears to be a trend towards localisation of grasshopper and locust management as an element of a general decentralisation. As grasshopper and locust programmes become more localised and site-specific, the other parameters of these efforts will inevitably change as well.

Cost of Management: External vs. Internal

As programmes are reduced in size, the rationale for federal (US) or international (Africa) funding is correspondingly diminished. The geopolitical unit of management becomes the determinant of funding, so that smaller-scale programmes are viewed as the responsibility of more localised governments (states in the US or nations in Africa).
To a certain extent, economics are both an effect and a cause of management localisation. That is, as funding to federal (US) and international (FAO) agencies declines, decentralisation becomes a necessity as much as a "strategy". The systematic effort to reduce federal spending in the US has undermined APHIS' capacity to sustain its grasshopper management programme, and presumably the US failure to maintain its payments to the UN may have affected FAO's ability to support international, locust control programmes.

**Timing of Pest Management: Reactive vs. Proactive**

Large-scale pest management programmes must overcome financial and logistical momentum in order to respond to an outbreak, and the attendant lag in mobilising such efforts can result in serious delays and agricultural losses. Although early warning systems are possible in theory, history suggests that the intensity of survey declines following the recession of major outbreaks, such that the next outbreak often begins without notice (Lockwood et al. 1988). Thus, the reduction in spatial scale may allow a shift from a reactive to a proactive or preventative programme that detects and suppresses incipient loci or "hot spots" of infestation. Again, cause and effect become confounded, as FAO's Emergency Prevention System (EMPRES 1998) was developed as a means of taking proactive measures on a more localised, but still multinational, basis. Indeed, it can be argued that a philosophical transition from treatment to prevention has played an important role in precipitating the downsizing of grasshopper and locust management.

**Constraints of Pest Management: Political vs. Economic**

With declining spatial, economic, and temporal scales of grasshopper and locust management, the limiting factor in developing and sustaining a pest management system is shifting from political to economic considerations. Rather than political pressure driving the availability of external resources, the matter is rapidly becoming a function of local economics (states in the US or nations in Africa). In the US, there has been a series of recent efforts to develop analytical and decision-support tools necessary to assess the economic benefit-cost ratios of control programmes, and reducing the cost of control has become a driving factor in the development of alternative management strategies (Lockwood and Schell 1997). In Africa, economic models have not been developed to assess the viability of local programmes, but it is clear that the rekindled interest in barrier treatments is, at least in part, motivated by the economic benefits of this strategy (Rachadi and Foucart 1996, Musuna and Mugisha 1997, Scherer and Célestin 1997, Wilps and Diop 1997, Launois and Rachadi 1997).

**Purpose of Pest Management: Expediency vs. Sustainability**

As the scale of pest management declines, the purpose of grasshopper and locust control is being reassessed. Again, it could be argued that the changing philosophy of pest management has been not only a consequence but a cause of this trend towards decentralisation. In any case, it is evident that the pest management systems that are developing for grasshoppers and locusts may become less influenced by political expediency. Although it is yet to be seen if the immense public pressure and consequent political repercussions associated with outbreaks of acridids in the US and Africa will be sufficient to once again re-establish the crisis-driven, reactionary pest management
programmes of APHIS and FAO, some evidence suggests that the pattern and philosophy of pest management may be changing. Rather than the periodic disassembly and reassembly of immense programmes in response to grasshopper and locust outbreaks, with assistance often arriving only after serious losses have occurred, the purpose appears to be shifting to developing sustainable, ongoing pest management systems under local control (e.g., the "hot spot" control programme (Lockwood and Schell 1995) and the EMPRES programme (EMPRES 1998, FAO 1998). Indeed, the growing interest in preventative programmes involving cultural and biological control (Lockwood and Schell 1997) reflects this underlying change in philosophy. Perhaps the most explicit evidence of such a transition is the statement by the US National Grasshopper Management Board (1995, 1998) that the purpose of control is to "keep good stewards on the land".

DECENTRALISATION: A COMPLEX OF COST AND BENEFITS

The rapidly changing conditions of area-wide pest management make the documentation of dynamics extremely difficult. As such, I shall rely heavily on my experiences with the effects of decentralisation of grasshopper management in Wyoming, with the hope that the reader will forgive my reliance on narrative evidence. To the extent possible, the case study of Wyoming will be related to apparent changes in Africa, but the nature of political communications and diversity of policies makes such extrapolations rather speculative.

Costs of Localising Pest Management

There are a number of costs associated with reducing the scale of grasshopper and locust control programmes, and without very careful and proactive leadership, these disadvantages may well lead to an ineffective array of disconnected efforts that fail to provide economic returns, food security or land stewardship.

Perhaps the most obvious cost of localisation is the loss of various economies of scale. The cost of insecticide, biological control agents, aerial application, etc., can all be expected to increase as the scale of programmes is reduced. In a related manner, there are likely to be inefficiencies with the fragmentation of management programmes. The border areas will be dramatically increased, so the integration of survey and management will be greatly complicated. For example, because surveyors are rarely located in the geographic centre of new, arbitrarily (politically, rather than ecologically) decentralised management units, these individuals are likely to terminate surveying at borders that are relatively proximate to their point of origin in one direction but travel to relatively distant borders in another direction (that would be much more efficiently sampled by an individual in the adjacent management unit). Indeed, we are seeing such logistical inefficiencies arising in Wyoming during the early development of a state-based survey programme.

The fragmentation associated with decentralisation may lead not just to inefficiencies but to actual conflicts of programmatic goals and strategies across an expanding network of boundaries. Differences in state-based surveys that are arising as a function of different perceptions of the purpose of grasshopper management and the consequent value of surveys will preclude any regional integration of survey data in the US. Conflicting programmatic goals are a particularly serious matter in the context of a highly mobile pest, such as the Desert locust in Africa. If one nation decides to wait
until swarms develop in order to organise a response (reactive or curative tactics) and an adjacent country has adopted a hopper band management programme (proactive or preventative tactics), then the success of the latter effort may be undermined by the strategy of the former. This concern can be conceptually expanded into the maxim that discord will arise when costs are individualised but the benefits are collectivised. That is, when early, preventative actions are taken in one locale, the adjacent areas may avoid the losses associated with an expanding outbreak (in the US) or a mobile swarm (in Africa). Hence, sustaining a decentralised mosaic of programmes in which we localise the costs and regionalise the benefits will be extremely difficult. This concern has been raised in the context of "hot spot" management in the US (Lockwood and Schell 1995), and it is evident that considerable energy and resources will be needed to assure that decentralised, smaller-scale programme are cohesive — or at least non-antagonistic — networks and to avoid the creation of area-wide pest management anarchy, in which fragmented units parasitise the benefits of prevention or pursue conflicting objectives across borders.

Finally, the current transition from large- to small-scale area-wide grasshopper and locust management can create considerable uncertainty and indecision. For example, the virtual elimination of the APHIS survey left states with no means of assessing the scale and intensity of ongoing grasshopper infestations as there was no systematic transfer of technology, infrastructure, or training. Hence, the sudden departure from federal to state responsibility has created a serious gap in our capacity to assess or respond to grasshopper outbreaks. In Africa, it appears that FAO has made a conscious effort to address the decentralisation of locust management through training and technology transfer, but it has yet to be demonstrated that nations or regions are prepared to respond to an outbreak. The history of external support via rescue efforts by APHIS or FAO entering a region when the grasshopper or locust situation becomes severe and politically untenable may undermine development of localised, management infrastructures. There are those who expect that when an acridid outbreak becomes sufficiently serious, the external agencies capable of imposing a system of area-wide control will be drawn back into the affected region. However, experience also suggests that this approach generates suboptimal solutions, as the lag time in mobilising large-scale interventions invariably permits extensive losses and precludes preventative strategies.

**Benefits of Localising Pest Management**

It would be misleading to suggest that decentralisation is necessarily a negative trend with respect to pest management. Reducing the scale of pest management has a number of possible and apparent benefits. As grasshopper and locust control programmes are localised, there may be greater participation by agriculturalists, as the immediate relevance of their efforts becomes apparent and their assistance becomes necessary. In Wyoming, we have seen a resurgence of interest by local (county) Weed & Pest districts with the diminishment of federal programmes. FAO efforts in Africa also have the potential to enhance local "ownership" of management programmes. Furthermore, as local agencies take on greater portions of the programmatic responsibilities, we can expect enhanced accountability and responsiveness. The Weed & Pest districts in Wyoming are under the control of local boards and funded by county taxes, so there is intense interest and scrutiny with respect to fiscal efficacy. In particular, the traditional overuse of insecticides that was possible through federal cost-sharing may soon become an obsolete strategy, as local funds are managed to optimise
economic benefits (Berry et al. 1994, Hastings et al. 1996). The consequent reduction in insecticide usage translates into not only increased economic returns but decreased environmental impacts as well (Lockwood and Schell 1997). When the distance between the source and the expenditure of funds is reduced via decentralisation, it is reasonable to expect that the attention to the efficient use of the funds will be correspondingly increased.

Interestingly, localised oversight has stimulated, rather than inhibited, innovation and risk-taking with respect to testing, adopting, and advocating new methods in Wyoming. This openness to novelty may be due to the realisation that the large-scale programmes of APHIS cannot simply be down-sized and forced into the local conditions. Our experience in Wyoming suggests that the adoption of the RAAT method and discussions of county-level surveys using the most recent innovations in sampling (Legg et al. 1993, 1996, Legg and Lockwood 1995) have been made possible (and necessary) by decentralisation; the old methods are simply inappropriate for the new scale. Indeed, the first studies of the RAAT method in the US were funded by, and conducted in cooperation with, two county-level Weed & Pest districts. Perhaps the frequency of, and apparent interest in, training programmes for locust management in Africa also reflects a willingness to explore new approaches (FAO 1998).

A related advantage of decentralisation is the potential for higher efficiency via site-specificity. It is clear that different habitats, landscapes, and production practices all generate localised ecological and economic situations, the response to which cannot be optimised by broad, federal policies and regionalised strategies. For example, the "hot spot" management method of suppressing outbreak by treating incipient loci of infestation is most effective when integrated with intense, site-specific knowledge of local pest species and habitats (Lockwood and Schell 1995). Indeed, FAO has concluded that, "... countries concerned with EMPRES are witnessing more efficient preventive control of pests. Response times to members' requests are shortening, and FAO staff in the field are in closer contact with the countries' needs" (FAO 1998).

CONCLUSIONS

The benefits and costs of an area-wide approach to grasshopper and locust management suggest that there may be no "ideal" scale for all aspects of a programme. It is safe to say that the maxim of "bigger is better" fails to adequately address the complexities of pest management, but the notion that "small is beautiful" oversimplifies the situation. Rather, it seems that different elements of a sustained area-wide pest management (as distinguished from the simpler objectives of a pest eradication programme) are optimised at different spatial scales. At this time, it appears that survey may be the sort of activity that is most efficiently conducted and coordinated over very large areas, due to economies of scale and with respect to logistics, consistency of training, standardisation of methods, uniformity of reporting and integration of information. Although there are also economies of scale with respect to treatment, it appears that site-specific or localised treatment programmes may yield greater economic and environmental returns, as well as more appropriate and timely responses to particular conditions. No matter what pattern of management emerges in the course of decentralisation, it will be critical to communicate and integrate across scales. While a mixture of management scales may be more complex that the historical, regionalised efforts of APHIS and FAO, it appears that there is considerable promise that a systematically integrated network of small- and large-scale responsibilities will result in
a more effective strategy than uniform scaling (either localised or centralised) without regard to the scale-dependent opportunities and difficulties of each management component.

REFERENCES


INTRODUCTION

Since 1981, the sterile insect technique (SIT) has been applied commercially for the control of the onion fly \( (Delia antiqua \) Meigen, Diptera: Anthomylidae) in the Netherlands, by a private company called de Groene Vlieg. This paper describes the practical application and problems encountered.

DESCRIPTION OF THE METHOD

The larvae of the onion fly are a severe pest in onions in temperate regions. In the Netherlands, onions are grown by individual growers on fields of approximately 2-6 hectares each. Onion fields are distributed among fields with other crops, and in areas where onions are grown, they account for about 5-10% of the surface area. The dispersal activity of the released flies is limited with the majority of sterilised flies remaining in the field where they were released. Therefore, it is possible for each individual farmer to use the SIT control method just as he would chemical control and this is independent of the types of control his neighbours apply. The application of SIT in this type of ecosystem is in direct competition with normal chemical control.

SIT is generally used as a population control method by reducing pest numbers or even causing local and temporary eradication. As low population levels are very difficult to monitor and immigration or passive transport of flies is rather common with the onion fly, eradication is not a feasible goal. Moreover, releasing a standard low number of sterile flies is more economical than trying to sustain barriers and monitoring for possible immigrants, at least for the time being.

Onion flies are mass reared by de Groene Vlieg. A new strain is regularly collected from the field, in or near the area where the releases take place. Flies which are released have been reared in the facility for 4-10 generations. Continuous rearing is carried out as young pupae can be stored for up to one year at 3°C. This ability to store pupae is extremely important for the implementation of the programme. The rearing capacity of the facility is over 400 million pupae per year and is used to treat about 2,600 hectares of onions, i.e., about 16% of the total Dutch onion crop area.

Onion fly pupae are sterilised shortly before emergence with gamma radiation from a Co-source. A few years ago, the Dutch government decommissioned a very appropriate radiation plant for pupal irradiation. Pupae have now to be irradiated in Belgium and this is expensive and inconvenient. The source is not really suitable for this purpose or to irradiate the volume of pupae required.

At emergence, the flies are marked with a fluorescent powder, which they retain in their retracted ptlinum. The flies are stored for a short period at 3°C and then loaded.
into the release containers by weight. Release containers consist of two gauze screens which form a cage of about 40 x 60 x 4 cm, each containing up to 40,000 sterilised flies. The flies are transported to onion fields by car. They are released by hand, the required number of release containers being emptied along the borders of the onion fields. Three traps are placed in every field and they are sampled weekly. During the first years of the programme, releases were made mainly from aircraft at a height of 20 m and a speed of 180 km/h. This method was abandoned for logistic reasons and for the fact that information on the distance between release site and trapping site could not be obtained.

Onion flies are removed from the traps and checked for the presence of dye. Flies without dye have to be taxonomically certified to be onion flies as there are several very similar fly species. The trap catch data are used to adjust the next release. This causes a considerable time pressure as releases are generally done weekly. Both sexes have to be released and while females have no effect on the technique, data from treatment can improve the information to be derived from the trap catches.

**PRACTICAL PROBLEMS**

The main problem is that the targeting of the fly population in an area-wide approach is only partially achieved. This means that the main economic advantage of SIT in area-wide application cannot be realised. The reason is the limited participation of growers due to their lack of confidence in the technique and the selfish behaviour of some growers.

The lack of confidence is due to the fact that most farmers are accustomed to easy application and the visible effects of chemical control. They put more trust in coloured powders (insecticides) applied by themselves all over the field, than they do in flies released onto their fields by other people. These flies can also fly to their neighbours' fields!

The initial cost to the farmer for the application of SIT was at first about one-third cheaper than chemical control. However, this wide difference in price turned out to be another reason for distrust – the farmers could not understand that a cheaper technology could give them the required level of control. Remarkably, the number of customers increased when the price was raised to about the level of the costs of chemical control. At present, the prices charged do not cover costs but making SIT more expensive than chemical control would lower participation much more.

During the first two years of its introduction, SIT was financially supported by the Dutch government. The government often reacts positively to new developments of benefit to the environment, but in the present case when the "newness" had worn away, the government retreated and left matters to market forces. This has been taken as a negative sign by the farmers and they are not clear why governmental support has been withdrawn.

Another cause of distrust in the farmers' eyes is that SIT "doesn't always work". This is due to the fact that at high population levels, SIT is much less effective than chemical control. The reason for this and the action taken are as follows. To reduce populations by a certain factor, the number of sterile flies to be released has to be related to the size of the wild population. However, growers are not at all interested in population levels and are only concerned with the prevention of damage, i.e., a certain low population level. So the higher the population density the stronger the reduction has to be. To achieve this, the number of flies to be released will have to be exponentially
dependent on the number of wild flies present. Thus, costs are also exponentially
dependent on the numbers of wild flies to be treated.

Chemical control, on the contrary, is based on prescribed treatment sufficient to
protect every single plant treated, irrespective of it being the only plant attacked or
whether, in fact, all plants being attacked. Treatment costs are independent of
population size.

This density dependent character of SIT makes competition with chemical
control difficult and as long as high population levels occur, it is at a disadvantage.
Once populations are reduced, SIT becomes very effective in comparison with chemical
control.

In the onion fly, variation of pest densities from field to field is considerable;
differences may reach a factor of 100. In silverskin onions and onion sets, population
levels can be especially high with the result that the number of sterilised flies required
easily exceeds the rearing capacity or financial constraints of the programme. Where
these crops are concerned, the flies are treated in an integrated approach. As soon as the
number of sterile flies required becomes difficult to produce, the grower is advised to
spray. About equal fractions of both fertile and sterile flies are thus killed, and releases
of sterile flies a few days later will result in better sterile to fertile ratios again.
However, growers are not concerned about the economics of SIT and they just observe
that "it doesn't always work".

Second, selfish behaviour by growers is a considerable problem. Difficulties arise
due to the growers who do not use SIT and who constitute some 40% of the onion
growers in the regions where it is marketed. Some growers prefer to use a cheaper
chemical control or, in fact, practise no control at all but simply hope to benefit from
sterile flies that are released in their neighbours' field. This selfish behaviour, generally,
does not work very well as the number of flies they receive will always be low and their
wild population will increase.

Every year, onions are grown in different fields. In spring, the flies emerging
from diapausing pupae, have to search for onions. This leads to a redistribution of
populations among onion fields. So, fields where flies have been insufficiently
controlled, or not controlled at all, have a major negative effect on the implementation
of SIT.

An overall reduction in pest population levels has only occurred in regions where
few onion sets or silverskin onions are grown, and where SIT has been applied for more
than ten years to over half of the fields.

In summary, the success of SIT against the onion fly in the Netherlands is
limited, due to the growers' trust in chemical control, a lack of governmental support,
the growers' interpretation of integrated control at high population densities as a sign
that SIT does not always work, and the selfish behaviour of some growers.

FUTURE PROSPECTS

Many growers who believe in, and use, chemical control tend to see SIT as a
convenient insurance policy in the event that chemicals would no longer be effective
due to the development of resistance. However, this is a dangerous option because when
resistance develops, the size of the population to be controlled will far exceed the
number of sterile flies that can be reared and released. Only strict and regional
management of onion production can provide a solution, but in the Netherlands, such a
degree of regulation is in practice impossible.
So at the moment, SIT can only be applied locally until elsewhere in the Netherlands the onion fly develops resistance to insecticides. This would give the opportunity to target nearly 100% of the onions in the present area under SIT treatment and for a better price. The other choice is to terminate the programme immediately and save any future losses.
The Sterile Insect Technique in the Integrated Pest Management of Whitefly Species in Greenhouses

M. Calvitti, P.C. Remotti and U. Cirio

ENEA, C.R. Casaccia Division of Agriculture and biotechnologies via Anguillarese 301, I-00060 S.M. di Galeria, Rome, Italy

INTRODUCTION

Insect pests commonly known as whiteflies are Hemiptera belonging to the family of Aleyrodidae Trialeurodes vaporariorum Westwood (greenhouse whitefly) and the B-biotype of Bemisia tabaci Gennadius (=Bemisia argentifolii Bellows and Perring) are pests whose economic importance is constantly increasing within the European agriculture. The B-biotype of B. tabaci, in particular, has become more problematic by causing damage over a wide range, from the temperate climates of Californian squash fields to European greenhouses and field crops. In the absence of valid alternatives, many growers have resorted to intensive application of insecticides to control these pests, creating a severe environmental and health hazard. Several new environmentally safe technologies are currently available and have opened up new opportunities in the integrated pest management (IPM) of whiteflies under greenhouse conditions. In particular, biological or biologically-based control means, including a number of fungi, insects, and compounds have been recently developed. However, the limitation of whitefly population outbreaks in greenhouses is a problem that needs to be solved.

The idea to extend the use of sterile insect technique (SIT) to a confined environment against whitefly species is novel, and especially when we consider that the target species undergo arrhenotoky (unfertilised females generate only male progenies). The possibility to join this approach to the IPM of the whitefly species in the greenhouse may open new perspectives in the safe application of nuclear technology for pest control. The present work reviews recent advances in research and practice related to the development of SIT for the control of whiteflies in greenhouses. Explanations on whitefly radiation biology, with data on Bemisia spp. radio-sterilisation, methods for whitefly mass rearing and collection, and the definition of a complete SIT procedure tested against the greenhouse whitefly on greenhouse tomatoes, are discussed in detail.

RADIATION BIOLOGY OF WHITEFLY SPECIES

Trialeurodes vaporariorum

Genchev (1986) first demonstrated the feasibility of sterilising males and females of the greenhouse whitefly by treating pupae or adults at the dose range 50-60 Gy. He found that γ-rays induced sterility in oocytes and as a result of lethal mutation transferred by spermatozoa, combined to partial sperm inactivation. These findings were later confirmed by Huang and Cirio (1989) who studied the radio-sensitivity of pupae of this species testing a 1-100 Gy dose range, 1-3 d before adult eclosion.
The results obtained from a successive series of laboratory tests (Calvitti et al. 1997) led to the following conclusions: 1) *T. vaporariorum* may be completely sterilised by treating adults with γ-rays at the dose of 50 Gy for females and 60 Gy for males, 2) sterilisation procedures do not affect insect longevity, 3) sterile males preserve a sufficient sperm transfer capacity, resulting in the transmission of dominant lethal mutations to progeny of untreated females. This capacity is highest in the first week after irradiation, and 4) sperm precedence, investigated with a computing P2 value, occurred for the sperm of the most recent copulation (Calvitti et al., unpublished data). We considered these results to be a valid basis for an extension of our studies on the greenhouse environment.

*Bemisia tabaci*

The same experimental procedure used to study the radio-sensitivity of the greenhouse whitefly (Calvitti et al. 1997) has been used to investigate the response of *B. tabaci* (B-biotype) to γ-rays. The results are summarised in Figures 1 and 2. Complete female sterility was achieved at 70 Gy. Males, tested over a 10-d period after irradiation, were less radio-sensitive. In fact, at 80 Gy, they were still able to fertilise a low percentage of eggs (0.01%). Furthermore, a higher resistance to irradiation of the silverleaf whitefly compared with the greenhouse whitefly, was observed. The analysis of the viability and fertilisation status of eggs laid by untreated virgin females that were mated with sterilised males, at various γ-doses (Figure 2), had the highest values of sterile male induced egg mortality (up to 51%) at 70 Gy. These findings confirmed that sterile silverleaf whitefly males produce spermatozoa still able to penetrate the eggs, generating non-viable embryos. This may play a key role in reducing the reproductive capacity of untreated females mated with treated males.

![Figure 1](image.png)

Figure 1. Effect of gamma irradiation on silverleaf whitefly fertility rate.
* Male fertility was considered 100% when crosses between virgin females and treated males produced at least 60% of female offspring (see Figure 2; 0 Gy).
Because of the possible transmission of plant disorders (silverleaf induction) and viruses by the sterile whitefly adults, open field and greenhouse experimentation of SIT is being delayed until the capacity of treated insects to act as vectors for viruses is fully clarified. However, Yokomi et al. (1990) demonstrated that the transmission of the squash silverleaf disorder is due to a toxicogenic factor associated with nymphal feeding.

EXTENSION OF SIT TO COMMERCIAL GREENHOUSES

Criteria for Selection in Experimental Greenhouses

An experimental application of SIT on a greenhouse scale, was set up in spring 1997 in two areas located in the province of Latina, central Italy. In this province, protected crops are widespread and T. vaporariorum is the dominant whitefly species. Extensive research previously published on the relationship between whiteflies and their natural plant hosts (Calvitti and Remotti 1998) contributed to additional information on the distribution and dynamics of the whitefly species in areas characterised by a high concentration of greenhouses. Whiteflies infest a greenhouse crop by 3 common routes: 1) acquired plant material or from older plantings of the same crops, 2) from weeds or other host plants occurring in the greenhouse, and 3) from host plants in the surrounding area.

According to the presence of whitefly susceptible crops, or weeds occurring in the areas around the greenhouses, two areas were identified for the study. The first one (area A), located at a sandy shore in a natural indentation, was characterised by a low concentration of greenhouses. In this area wild erbaceous plants growing around the greenhouses are generally removed. The second (area B), was characterised by widespread greenhouses and abundant weed hosts for whiteflies. In both areas, we
selected 16 unheated greenhouses of about 500 m², half of which were provided with a 50-mesh screen along the sides, to prevent migratory insect flow. For each area, eight greenhouses were used for SIT trials (four screened and four opened). The remaining eight greenhouses were not subjected to any treatment against whiteflies and were used as controls. In all greenhouses, tomato (Lycopersicon esculentum Miller) cultivar "Monica" plants were transplanted at the beginning of March 1997.

**Whitefly Mass Rearing, Collection and Irradiation**

Mass rearing of the greenhouse whitefly is feasible at an acceptable cost as shown by the commercial production of its parasitic wasp Encarsia formosa Gahan (Hymenoptera Aphelinidae). A mass rearing facility for the whitefly sterile insect campaign was developed at the ENEA-Casaccia research centre (Rome). An isolated heated (T= 25 ± 5°C) greenhouse of ca. 120 m² was filled with the same proportion of eggplant (Solanum melongena L.), tomato and zucchini (Cucurbita pepo L.) plants, grown in pots and placed on four benches of 12 m² (60 plants per bench). Plants were irrigated and fertilised abundantly. Four weeks prior to starting the campaign, some hundred adult whiteflies were released and allowed to spread and multiply in this greenhouse. Insects were captured in a greenhouse where the plants did not show any symptoms of pathology. All plants were soon colonised with enough insect offspring for the latter experiments. The scheme of whitefly production required the replacement of damaged plants not able to sustain high whitefly population. It was possible to collect about 300 adults per plant per day. The adults, normally migrating to the upper part of the plants, were collected with a modified aspirator into petri dishes that had black cheese cloth on the bottom. The collected insects were stored at 4-6°C and counted with an image analyser. Each petri dish contained approximately 1,000 to 2,000 adults. The dishes were successively irradiated at 55 Gy and transported in a cool box to the greenhouses.

**Sterile Insect Release**

SIT protocol was defined according to the availability of insects and to the presumed reproductive capacity of the whiteflies. Sterile insects were released into greenhouses at 10-d intervals in order to ensure a continuous supply of sexually active sterile males, for a total of six successive releases. The number of sterile whiteflies (sex ratio 1:1) released, varied from 10 (first release) to 50 insects per plant in each of the last two releases. The complete sterile insect release schedule is shown in Figure 4. We avoided overloading the young plants with sterile insects, although it was demonstrated that sterile whiteflies were not able to cause direct damage to plants due to their feeding activity, confining the effective crop injury to nymphs of the native population (Calvitti et al. 1998). About 200 sterile whiteflies per plant (ca. 120,000 per greenhouse) were released over the experimental period. In each of the two areas, we applied SIT protocol both on the four screened and four opened greenhouses. The same programme of sterile insect release was applied to all the greenhouses selected for SIT trials.

**Sampling Procedure**

Prior to the release of the sterile whiteflies, the initial population density of the greenhouse whiteflies was estimated. Since the plants were monitored in the first week after transplant, only the adult stage was monitored. All plants were checked early
morning because the adults are less mobile due to the lower temperatures. Since we considered the application of SIT against whiteflies as a preventive measure, we did not select for our purpose, greenhouses in which the adult whitefly density exceeded the mean value of 1 to 2 pairs of adult whiteflies per plant. Yellow sticky were applied to traps around the greenhouse (one trap every 10 m) in order to acquire additional information on the whitefly migratory flow. Traps were replaced at 10-d intervals and the adults trapped were counted (Figure 3).

![Graph showing whitefly trap catches in A and B areas over 90 days.](image)

**Fig. 3.** Mean 10-d whitefly trap catches in A and B areas.

The greenhouse whitefly population was analysed over a 90-d period. Due to the presence of sterile adults, we monitored the density of nymphs (L3 and L4) and pupae by a random sampling of 10% of plants located in the greenhouses. We used the leaf as the sample unit by removing three leaves from the upper, middle and lower sections of plants. All the greenhouses were subjected to the same programme of chemical treatment as any commercial crop except that no insecticides were applied. At the end of the experimental period, all mature fruits were harvested from the different classes of the greenhouses and examined to determine the mean percent of fruits coated with honeydew and mould formation.

**SIT Evaluation**

The application of SIT treatment resulted in a slower population increase in all four different environmental conditions (Figure 4). Absolute population reduction was not achieved, nor could this be expected, due to the parthenogenesis of these insects.

It should be emphasised that after 90-d, the differences in whitefly density, between treated and untreated crops, were remarkable, particularly in the greenhouses in area A, characterised by low presence of whitefly fliers in the outside environment (Figures 3, 4a and b). In this area, the application of 50-mesh screens did not result as an essential measure.
Fig. 4. Density trends of whitefly scales (3\textsuperscript{rd} and 4\textsuperscript{th} instars) and pupae in greenhouses of area A (a-b) and area B (c-d). Arrows and numbers show the releases of sterile insects valid for all SIT greenhouses.
Area B was characterised by abundant fliers in and outside the greenhouses (as shown by the adult mass trapping) (Figure 3). In greenhouses lacking a screen along the sides, the efficacy of SIT application resulted in a decrease. In fact, the delaying effect on the natural drift of whiteflies to population outbreaks (Figure 4c and d) was not remarkable. Because of the constant input of insects from the outside, the sterile insect technique did not work sufficiently well to achieve a significant retardation of the population increase. Whiteflies could develop up to the mean density of 400 scales per leaf in spite of the slowing effect of SIT. The isolation of greenhouses achieved with net-screens proved a very useful measure. In fact, this study has demonstrated that the joint use of screens and sterile insects retarded the whitefly population increase by as much as ca. 50%.

The qualitative analysis of tomato fruits, performed at the 90th d, showed that the differences found in the population densities did not consistently result in a different quality of fruits. In area A, whiteflies did not cause any damage to plants in treated or in untreated greenhouses, thereby confirming that the release of sterile whiteflies could not cause damage to the crop.

In area B, we observed honeydew and mould on 12.2 $\pm$ 3.8% of harvested fruits from untreated and unscreened greenhouses. The application of net-screens as a unique measure to prevent whitefly input reduced the mean value to 8.6 $\pm$ 2.1%. Approximately, the same percentage of contaminated fruits was recorded when SIT was applied in greenhouses lacking screens (7.6 $\pm$ 2.0). The most notable results in terms of whitefly population growth reduction and fruit quality (1.5 $\pm$ 1.1% of fruits with honeydew deposits) were achieved when SIT was coupled with the application of 50 mesh-screens.

Application of SIT against whitefly species, under greenhouse conditions, may work well as a preventive measure by delaying significantly the occurrence of population outbreaks, which causes relevant economical damage. This role may become of primary importance in relation to short period greenhouse crops.

The sterile insects do not cause damage to plants as previously shown on zucchini plants (Calvitti et al. 1998), and the results obtained on tomatoes have confirmed this. We may presume that since sterilised females lay fewer eggs only in the first week after irradiation, they probably require less food. Research is in progress to verify this, which is fundamental to determine whether or not sterile whiteflies completely preserve the capacity as viral vectors.

The results obtained on greenhouse tomatoes suggest that SIT worked better in greenhouses not exposed to high migratory pressure. This pressure depended on the ecological characteristics of the area and was reduced by applying net-screens. Nevertheless, we believe that SIT may be considered a useful tool in supporting the augmentative biological control of whiteflies. SIT is not limited either by adverse climatic conditions or the use of agro-chemicals. The only limiting factor now is incomplete knowledge of the physiological effects on plants associated with the excessive pressure of sterile whiteflies.

REFERENCES


Area-Wide Integration of Lepidopteran F₁ Sterility and Augmentative Biological Control

James E. Carpenter

Insect Biology and Population Management Research Laboratory, Agricultural Research Service, United States Department of Agriculture, Tifton, Georgia, USA

INTRODUCTION

Area-wide pest management (APM) and integrated pest management (IPM) originated from two different efforts to combine two or more control techniques into programmes in which each method could synergise the effectiveness of others and thus create a level of pest control that was greater than that of a single technique (Perkins 1982). Since then, the concept of APM has evolved to include many aspects of IPM and often is now referred to as area-wide IPM. Still, the element of total population management is central to this approach of insect pest management. In support of APM, Knipling (1998) stated that of the insect pests that were of major concern to agriculture before the newer classes of insecticides were available, most are still pests today, the major exceptions being the screw-worm fly and the boll weevil in the southeastern US cotton growing region. Knipling also noted that both of these pest species were subjected to area-wide suppression programmes. In response to the USDA IPM Initiative (USDA 1993, 1994) which seeks to achieve the national goal of having 75% of the crop acres under IPM by the year 2000, the Agricultural Research Service developed an Area-wide IPM Programme. This programme combines environmentally-sound pest control techniques with the advantages of APM and develops partnerships with other federal, state, local and private sector entities. Technologies such as the integration of lepidopteran F₁ sterility and augmentative biological control may be considered for future programmes.

EFFICACY OF F₁ STERILITY AND AUGMENTATIVE BIOLOGICAL CONTROL

The ability of the F₁ sterility technique to impact upon seasonal populations of highly mobile lepidopterans was demonstrated on *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae). Carpenter and Gross (1993) conducted a pilot test in small mountain valleys in North Carolina to assess the influence of released, substerilised (100 Gy) males on wild *H. zea* populations and to measure the infusion rate of inherited sterility into the wild population. Results from this study revealed that the number of wild males captured per hectare was positively correlated with the distance from the release site of irradiated males. Analyses of seasonal population curves of wild *H. zea* males calculated from mark-recapture data suggested that seasonal increases of wild *H. zea* males were delayed and/or reduced in mountain valleys where irradiated males were released. The incidence of larvae with chromosomal aberrations (progeny of irradiated, released *H. zea* males (Carpenter 1991) collected from the test sites during the growing seasons indicated that irradiated males were very competitive in mating with wild
females and were successful in producing F1 progeny which further reduced the wild population. Overall, release ratios averaged <5:1 but reduced the wild population of *H. zea* by more than 70%.

Augmentative releases of parasitoids also have the potential to moderate the seasonal increase of lepidopteran pest populations. For example, a 3-yr test was conducted to examine the ability of augmentative releases of the tachinid parasitoid *Archytas marmoratus* (Townsend) (Diptera: Tachinidae) to control early season populations of *H. zea* (Proshold et al. 1998). Percentage parasitism of *H. zea* was increased to 42% in non-isolated fields of whorl-stage corn and >90% in isolated fields following inundative releases of *A. marmoratus*. In a contiguous corn growing area, there was a positive correlation between density of *H. zea* larvae and percentage parasitism within 0.8 km of the release field. The field with the greatest larval density and percentage parasitism of *H. zea* larvae was the one farthest from the release site, indicating good host finding capability by *A. marmoratus*.

The potential benefit of combining sterile insects with conventional pest control methods was recognised by Knipling (1964). Later, researchers studied the idea of combining sterile insect releases with the release of parasitoids to improve the efficiency and efficacy of pest control (Barclay 1987, Wong et al. 1992). According to Knipling (1992) and Barclay (1987), combining inundative releases of natural enemies and sterile insects should yield synergistic effects. Although natural enemies and the sterile insect technique have different modes of action, the effectiveness of the sterile insect technique increases the ratio of natural enemies to adult hosts and the effectiveness of natural enemies increases the ratio of sterile to fertile insects. However, greater suppression could be expected if parasitoid releases were combined with the F1 sterility technique (Carpenter 1993). Not only is F1 sterility theoretically more effective than full sterility in reducing population increases (Carpenter et al. 1987), the F1 sterility technique produces sterile F1 larvae that would provide an increased number of hosts for the parasitoids. As a result, the number of parasitoids produced should increase even if the rate of parasitism remained the same (host density independent) and whether or not additional parasitoids were released. Although population models that independently consider augmentative releases of parasitoids (Knipling 1992) and F1 sterility (Carpenter et al. 1987) suggest both tactics are highly efficacious, integrating lepidopteran F1 sterility and augmentative biological control results in synergistic effects (Carpenter et al. 1996b). Therefore, the full potential of F1 sterility and of augmentative releases of parasitoids as area-wide control tactics for lepidopteran pests may be realised only when the two suppression methods are integrated.

Population models may provide some insight into how different control strategies could be combined for greatest efficiency. Although the effectiveness of F1 sterility continues to increase as the ratio of irradiated to non-irradiated insects increases, the efficiency decreases quickly once a 10:1 ratio has been obtained. A similar loss of efficiency occurs in the parasitoid release technique when the parasitoid to host ratio increases above 5:1 (Carpenter 1993). According to these models, the economic benefit of combining F1 sterility and parasitoid augmentation techniques would be greatest when the ratio of irradiated to non-irradiated is <10:1 and the ratio of parasitoid to host is ≤5:1.

The model presented in Figure 1 demonstrates that population suppression is increased when F1 sterility and parasitoid releases are combined and that the percentage reduction in normal pest population growth is greater when parasitised host produce adult parasitoids than when no parasitoids are produced. However, the number of parasitoids produced from parasitised hosts following an inundative release of
parasitoids is difficult to predict. As the parasitoid:host ratio increases, super-parasitism and, consequently, parasitoid mortality may also increase. During 1993 when *A. marmoratus* were released against *H. zea* larvae in whorl-stage corn, the rate of parasitism was very high and super-parasitism was quite common (Proshold et al. 1998). Consequently, few flies were produced from the parasitised *H. zea* collected from the field.

![Percent Reduction in Normal Population Growth](image)

Figure 1. Comparison of the projected reduction in normal population growth when only parasitoids are released, when only irradiated (100 Gy) male moths are released, when both parasitoids and irradiated males are released and no parasitised host produces parasitoids and when both parasitoids and irradiated males are released and all parasitised hosts produce a parasitoid. (Carpenter et al. 1996b).

**COMPATIBILITY OF F1 STERILITY AND AUGMENTATIVE BIOLOGICAL CONTROL**

Fully successful integration of *F1* sterility and parasitoid augmentation into a management approach can occur only if parasitoid strategies do not negatively impact irradiated insects and their progeny more than that of the wild population and if *F1* sterility does not negatively impact upon the efficacy of parasitoids. Knowledge of any negative impact of *F1* sterility on parasitoids would be important before an APM programme using *F1* sterility was implemented. For example, if parasitoids that attacked *F1* were unable to develop normally and most of the host larvae present were *F1* larvae, there could be a negative impact on subsequent parasitoid populations. Conversely, if parasitoids were able to develop normally on *F1* eggs, larvae and pupae, the greater number of hosts available should allow for a subsequent increase in the parasitoid population. Because many hosts of the *F1* generation would die before they reached the adult stage, any parasitoids developing on these hosts would result in a positive and synergistic increase in the efficacy of the APM programme.

Field, greenhouse and laboratory studies compared the acceptability and suitability of progeny from irradiated (100 Gy) and non-irradiated *Spodoptera exigua* (Hubner) (Lepidoptera: Noctuidae) males as hosts for the larval parasitoid *Cotesia*
marginiventris (Cresson) (Hymenoptera: Braconidae) (Carpenter et al. 1996a) and progeny from irradiated (100 Gy) and non-irradiated *H. zea* males as hosts for *A. marmoratus* (Mannion et al. 1994, 1995). Results from these studies revealed that progeny of irradiated male and non-irradiated female moths were acceptable and suitable hosts for parasitoid development. Female parasitoids showed no oviposition preference for progeny from females paired with either irradiated or non-irradiated males. Other researchers studying different lepidopteran pests also are considering the possibility of combining F1 sterility and parasitoid augmentation into an effective management approach (Anonymous 1996).

Carpenter (1993) described several different scenarios in which F1 sterility could be integrated with natural enemies to control pest lepidopteran populations. The release of partially sterile male and female moths would produce large numbers of F1 eggs and larvae that could be field-reared on early season weeds, or reared on crop plants that could tolerate some feeding damage (e.g., whorl-stage corn) by the larvae. Natural enemies (native and/or released) could use the F1 eggs and larvae as hosts and, thereby, substantially increase the natural enemy population for the next generation of the pest insect. Also, surviving F1 larvae would produce sterile adults that would negatively impact the next generation of the pest insect. If the economic injury level of cultivated host plants indicated that the additional F1 larvae were undesirable, the dose of radiation administered to the target pest could be increased to a level that would reduce or eliminate the number of progeny from irradiated females, or releases could be limited to irradiated males.

Although F1 sterility is compatible with synthetic organic insecticides, parasitoids and/or predators are not generally compatible with these products. If insecticides are needed to reduce pest infestations, insect growth regulators, biologicals, or other formulations that are compatible with natural enemies should be considered.

Another management scheme could be to establish host plants for the lepidopteran pest in insecticide-free areas adjacent to insecticide-treated crops. Host plants could be artificially infested with pest larvae to provide natural enemies (native and/or released) with an adequate supply of hosts. If the pest larvae used in the artificial infestations (nursery crops) were sterile (progeny of irradiated parents), then non-parasitised larvae would not contribute to the increase of the wild population, but would produce sterile adults that would negatively impact the next generation of the pest insect.

**CHALLENGES AND CONSTRAINTS**

Although many studies have demonstrated that F1 sterility is much more effective than full sterility in producing competitive, irradiated male moths and in reducing populations of the target pest (Anisimov et al. 1989, Anisimov 1993, Carpenter et al. 1983, Proverbs et al. 1978), researchers have been reluctant to recommend substerilising doses because of concerns that hatching F1 larvae from irradiated females would cause unacceptable or economic damage to the cultivated crop. These concerns are valid, especially when the crop has a high cash value and can tolerate little or no damage and/or when release ratios of irradiated: wild are >10:1.

In an attempt to better understand the potential damage to plants by F1 larvae, a model is being developed to predict the influence of different parameters on larval populations resulting from increasing release ratios of partially sterile : wild moths. The general form of the model is as follows:
when \( f \) = number of female moths/area; \( d \) = number of plants/area; \( e \) = number of eggs laid/female; \( s \) = \% survival of larvae to adulthood excluding any effect of augmentative biocontrol; \( p \) = \% surviving the effects of augmentative biocontrol; \( h \) = \% of eggs hatching; \( M_i \) = probability of mating for each type of male moth present; and \( l_j \) = number of larvae/plant resulting from a specific cross. If irradiated (I) males and females have been released into a wild (W) population, then \( l_j \) must be calculated for each of the 4 possible crosses (i.e., \( l_{WW}, l_{WI}, l_{IW}, l_{II} \)). Therefore, the sum of all \( l_j \) = the total number of larvae/plant. Also, \( M_I + M_W = 1.0 \) for each female type (W&I) when \( M_I \) is calculated as the number of “I” males present divided by the number of all males present and \( M_W \) is calculated as the number of “W” males present divided by the number of all males present.

When the number of larvae/plant needed to reach the economic threshold (\( l_i \)) is known, the number of females/area (\( f_i \)) required to reach the economic threshold can be calculated by modifying equation (1) as follows:

\[
f_i = dl_i/esp\ (2)
\]

Although this model is incomplete in its present form, it provides a general estimate of how different release ratios of irradiated moths will affect the population of larvae in the field when subjected to simultaneous releases of a natural enemy such as a parasitoid. The data represented in Figure 2 were summarised from radiation biology studies (Anonymous 1993, Carpenter and Malakrong, unpublished data) of the diamondback moth, \textit{Plutella xylostella} (L.) (Lepidoptera: \textit{Yponomeutidae}), irradiated at 150 Gy. The economic threshold, plant densities and expected parasitism of released \textit{Cotesia plutellae} Kurdjumov (Hymenoptera: \textit{Braconidae}) were estimated from Biever et al. (1994) and data provided by the Ministry of Agriculture, Mauritius. The number of wild females/area needed to produce an economic threshold of 3 larvae/plant was estimated at 850 and the sex ratio was set at 1:1. Other estimates included: \( e = 100; d \leq 10,000; s = 0.7; p = 0.5; h_{WW} = 100%; h_{WI} = 50%; h_{IW} = 10%; h_{II} = 10\%\). This model estimates that the total number of larvae resulting after a release of irradiated male and female moths will not exceed the number of larvae that would occur naturally, as long as the release ratio of irradiated : wild does not exceed 4:1 (Figure 2). If the economic threshold were lower and thereby requiring fewer larvae, adjustments would be necessary such as releasing only irradiated males, releasing fewer females, or increasing the dose of radiation. The \% of larvae that are \( F_I \) sterile increases as the release ratio of irradiated : wild increases (Figure 2). At a release ratio of 4:1, approximately 84\% of all larvae in the field would be \( F_I \) sterile larvae. The effect of the rate of survival (\( s \)) on the number of larvae present at different release ratios is presented in Figure 3. The model predicts that an increase in the rate of survival from \( s = 0.7 \) to \( s = 0.9 \) would have almost no effect on the number of larvae present.

**SUMMARY**

Augmentative biological control and \( F_I \) sterility in Lepidoptera have emerged as promising control strategies for lepidopteran pests. The potential for combining these two pest management tactics has been examined by laboratory, greenhouse and field studies. Results from these studies have revealed that progeny of irradiated Lepidoptera and progeny from non-irradiated Lepidoptera are equally acceptable and suitable as...
Figure 2. Model showing the effect of the number of released, irradiated DBM on the number of larvae per plant and the percentage of those larvae that are progeny of irradiated parents ($F_1$ sterile larvae). The economic threshold is set at three larvae per plant. Data points on the graph represent values calculated at different release ratios (0:0:1:1; 1:1:2:2; 1:1:1:1; 2:2:1:1; 3:3:1:1; 4:4:1:1; and 5:5:1:1) of irradiated males : irradiated females : wild males : wild females.

Figure 3. Model (as in Figure 2) comparing the number of larvae per plant for two different survival rates (70% and 90%).
hosts for natural enemy development. Integration of $F_1$ sterility and augmentative releases of natural enemies should yield synergistic effects, especially at release ratios of $<10:1$. Even lower release ratios of natural enemies have proved to impact pest populations and lower release ratios of irradiated moths would reduce the probability that $F_1$ sterile larvae would cause economic damage to crops.

REFERENCES

Anisimov, A.I. 1993. Study of the mechanism and possibilities of using $F_1$ sterility for genetic control of codling moth. In Radiation Induced $F_1$ Sterility in Lepidoptera for Area-Wide Control, IAEA-STI PUB/929, Vienna, Austria. pp. 162.


Carpenter, J.E., A.N. Sparks and H.L. Cromroy. 1987. Corn earworm (Lepidoptera:
Integration of Lepidopteran $F_1$ Sterility and Augmentative Biological Control


US Department of Agriculture. 1994. USDA announces national plan to increase use of integrated pest management, Release Number 0943.94; and Background: USDA's IPM Initiative, Release Number 0942.94, Office of Communications, USDA, Washington, D.C.

Pink Bollworm Integrated Management Using Sterile Insects Under Field Trial Conditions, Imperial Valley, California

M.L. Walters¹, R.T. Staten¹ and R.C. Roberson²

¹ USDA, APHIS, PPQ, Phoenix Plant Protection Center, Phoenix, AZ, USA
² California Department of Food and Agriculture, Sacramento, CA, USA

INTRODUCTION

The pink bollworm moth (Pectinophora gossypiella Saunders) feeds almost exclusively on cotton (Gossypium spp.) and causes economic loss (Pfadt 1978). The pink bollworm (PBW) is often the key pest of cotton in Arizona, southern California, and northwestern Mexico. The larvae (immature stages) bore into the developing cotton fruit, where they feed on the cotton lint and seeds, causing significant damage and dramatically reducing the yield of cotton lint (Pfadt 1978). The PBW is difficult to control with conventional means (insecticides) because it spends the destructive larval phase inside the cotton boll where it is well protected from control measures. Cultural controls, such as a short growing season, have successfully decreased the population in the Imperial Valley (Chu et al. 1992) to the point where eradication may be possible using sterile insects and genetically engineered cotton. Because the PBW is an introduced insect, with few plant hosts other than cultivated cotton, its eradication from continental USA is a desirable and economically attractive alternative to the continued use of pesticides and/or further loss to the pest.

Mass releases of sterile insects began in earnest in 1970 in the San Joaquin Valley, California, in order to inhibit normal reproduction and to eradicate the pest in an environmentally responsible manner. Sterile release involves mass production and sexual sterilisation using irradiation (20 krad for PBW adults). This was accomplished by building a rearing facility in Phoenix, AZ. The facility has 6,410 square metres of permanent laboratories, rearing and irradiation chambers and insect packing rooms. The facility operates the year round but with a variable production rate, that is, maximal during the cotton growing season (May through September).

Sterile insect technology is based on the monitoring of the native and sterile populations in the field and the subsequent release of appropriate numbers of sterile insects in order to inundate the native population and drastically reduce native to native mating. Sterile release has protected the San Joaquin Valley from developing a reproducing PBW population but cannot prevent wind-borne immigration from other infested areas.

THE IMPERIAL VALLEY STERILE RELEASE PROJECT

The overall objective of this programme was to test the effectiveness of sterile insects, used in combination with pheromones, in a generally infested, optimum season, area. Insect populations were monitored and population data were collected using ca. 200 pheromone baited Delta traps (Foster et al. 1977) at no less than two traps per cotton field. Four traps were used in fields of more than 28 hectares. Sterile and native
male moths were attracted by the lure and became stuck in the trap. Twice per week, field technicians checked the traps, counted native and sterile moths captured, and cleaned or replaced the traps. They recorded the trap catches on a preprinted, automated data entry sheet. Project management used the field data to regulate the rates of the release of sterile PBW moths and application of pheromones, as described below.

In the years 1994-1996, moths were aerially released six days a week (Table 1), from the time before cotton fruit was available until after fruit was available or until we could no longer hold a beneficial sterile to native ratio. Specifically, sterile release began in all fields on or before four true leaves were found on plants, and at the same rate in all fields. There were four release rates available. The rate was determined by the risk, calculated from native and sterile moth trap data, and limited by moth availability. When plants reached the 6th leaf stage, if a 60:1 ratio was not obtained, the Mitsubishi® PBW rope pheromone formulation was applied at 400/acre (Staten et al. 1987). During mid-season, if a good ratio of native:sterile moths could not be obtained at the highest release rate (4x), a sprayable pheromone formulation was used with three applications (Ecogen MEC® at 5 grams a.i./acre). “Pheromone” refers to an artificial sex pheromone that mimics the chemical mixture of substances secreted by female PBW moths. The female uses the natural pheromone to signal to and attract a male for mating purposes. The artificial pheromone has a similar effect on the male but since it is distributed all over the cotton field, it confuses or incapacitates the male so that he cannot find a female and thus reproduction is suppressed. Pheromone applications integrate well with sterile releases and pheromones are also used to bait the sticky traps used for population monitoring.

A Cessna 206 aircraft was used as the delivery aircraft. The seat rails were used to fasten the insect delivery machine and refrigeration equipment to the aircraft body. A drop tube installed through the aircraft skin allowed the insects to be metered out into the slipstream. Modifications to the air conditioning improved efficiency and, subsequently, increased insect quality. A new auger system, in conjunction with a stepping motor drive, improved calibration and allowed rate changes during the flight. Video card camera technology provided direct visual monitoring of insect discharge. The camera assured the pilot that the system was operating and that all insects had been discharged before the termination of the flight.

The geographic coordinates associated with a sample, such as trap captures, were input into a geographic information system (GIS) and correlated with other data layers. The total GIS has multiple functions: it serves as the basis for data analysis and output of recommendations.

Table 1 describes the control measures used from 1994-1996. In 1995, we experimented with a low-level sterile release in an effort to find a very affordable, yet effective level of release. We found this level insufficient to control the PBW population and so returned to a higher level in 1996, with good results.

In 1997, due to the widespread use of genetically engineered cotton, moths were released three days a week from mid-May through July at a rate of 40 insects/hectare/day. Note in Figure 1 that although local reproduction was heavily suppressed by genetically engineered cotton, sterile insects and pheromones, late season moth numbers were similar to those of previous years. These catches seem to be correlated more to migration from cotton acreage to the south than to actions taken in the Imperial Valley. Migration is indicated by increasing numbers of PBW intercepted in traps located between the two growing areas. This evidence supports the need for expansion of the PBW management area.
Table 1. SIT and Pheromone Parameters for 1994-1997.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sterile moths/hec</td>
<td>100</td>
<td>70</td>
<td>140</td>
<td>40</td>
</tr>
<tr>
<td>Pheromones</td>
<td>Rope &amp; MEC</td>
<td>Rope &amp; Fibre</td>
<td>Rope and Fibre</td>
<td>Rope</td>
</tr>
</tbody>
</table>

Imperial Valley, 1997

Figure 1. Wild PBW males trapped in the Imperial Valley, California, 1994-1997.

The cotton planted in the Imperial Valley in 1997 consisted of 81% genetically engineered cotton, 17.5% conventional (non-genetically engineered, susceptible) treated with pheromone rope and 1.5% conventional untreated refuge. Defoliation began in mid-August. Bolls sampled after that time were taken from a diminished boll population and were under heavy pressure from increasing PBW activity. Late season samples were heavily biased toward high PBW levels, as reflected in the boll data (Table 2).

1998 AND BEYOND

The objective of eradication is being pursued as an expanding, multi-season project. In 1998, sterile insect coverage was extended to the California Blythe/Palo Verde Valleys. Widespread use of genetically engineered cotton in these two growing areas began in 1997.

Genetically engineered cotton plants produce the Bacillus thuringiensis (Bt) toxin. Most Lepidoptera cannot survive ingestion of the toxin and thus cannot reproduce on these cottons. With genetically engineered cotton, we expect high larval mortality in early instar, a few surviving larvae found in the 1-3% non-Bt producing plants found within the cultivar, and a drastic reduction of PBW biotic potential. However, the use of genetically engineered cotton may be short-lived due to resistance. By late season, 95 %
of remaining bolls will have eggs laid on them and have 1st instar penetration. This increases resistance pressure. Genetically engineered cotton alone will not eradicate the pest since the producing company requires a certain percentage of cotton to be planted in conventional, susceptible cotton varieties. This is to protect against the rapid development of resistance to the toxin.

Table 2. Boll data for 1997, Imperial Valley, California.

<table>
<thead>
<tr>
<th>Week of</th>
<th>100 % Genetically Engineered cotton</th>
<th>Conventional Cotton</th>
<th>Weighted Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bolls Sampled</td>
<td>Larvae/100 Bolls</td>
<td>Bolls Sampled</td>
</tr>
<tr>
<td>6/22/97</td>
<td>2000</td>
<td>0.00</td>
<td>1000</td>
</tr>
<tr>
<td>7/6/97</td>
<td>2000</td>
<td>0.00</td>
<td>1000</td>
</tr>
<tr>
<td>7/20/97</td>
<td>1990</td>
<td>0.00</td>
<td>975</td>
</tr>
<tr>
<td>8/3/97</td>
<td>1998</td>
<td>0.00</td>
<td>995</td>
</tr>
<tr>
<td>8/17/97</td>
<td>1383</td>
<td>0.00</td>
<td>280</td>
</tr>
<tr>
<td>8/31/97</td>
<td>1148</td>
<td>0.00</td>
<td>606</td>
</tr>
<tr>
<td>9/14/97</td>
<td>322</td>
<td>0.31</td>
<td>519</td>
</tr>
<tr>
<td>9/28/97</td>
<td>200</td>
<td>0.00</td>
<td>203</td>
</tr>
</tbody>
</table>

The combined effect of sterile insects and genetically engineered cotton may make eradication possible in a relatively short period and the potential for resistance forces a short time frame. We use the term "eradication" to indicate zero detection with an extensive survey for three years following completion of programme. The first two years of the eradication effort entail the highest costs (Table 3). Since the PBW is a highly mobile insect, the programme must encompass large contiguous areas. Suppression (control) must be intensive for at least two years and must start where the pest has maximum biological potential. The programme must include a large area such as southern California, Baja Norte, northern Sonora and western Arizona. Cultural controls must be used including early plough down, a host free period and clean seeds. The monitoring of native and wild populations and good information management are critical to making optimal resource allocations. Mating disruption with several forms of synthetic pheromones greatly enhance the effectiveness of the programme, especially when wild moth population pressure increases. Pheromone rope formulations must be used at adequate levels and with proper timing (6 true-leaf stage). Pheromone fibre may be applied later in the season to thwart immigrating populations. The release of sterile PBW is a key component to the overall success of the programme and is recommended for active eradication/control areas. The final component is the partnering of cotton growers with state and federal agencies.
Table 3. Estimated costs for a sample eradication scenario, first 2 years.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Hectare</th>
<th>Seasonal Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>125 sterile insects/day * 60 days = 7,500 insects/hectare @ US$30/hectare</td>
<td>80,000</td>
<td>US$ 2,400,000</td>
</tr>
<tr>
<td>Genetically engineered cotton @ US$80/hectare</td>
<td>72,000</td>
<td>US$ 5,760,000</td>
</tr>
<tr>
<td>High rate pheromone @ US$70/hectare</td>
<td>8,000</td>
<td>US$ 560,000</td>
</tr>
<tr>
<td>Mid-season pheromone application @ US$25/hectare</td>
<td>8,000</td>
<td>US$ 200,000</td>
</tr>
<tr>
<td>Monitoring costs @ US$12.50/hectare</td>
<td>80,000</td>
<td>US$ 1,000,000</td>
</tr>
<tr>
<td>Total costs per growing season @ US$124/hectare</td>
<td>80,000</td>
<td>US$ 9,920,000</td>
</tr>
</tbody>
</table>

PROGRAMME RESULTS AND CONCLUSIONS

Sterile pink bollworm moths have been released in the San Joaquin Valley, California, USA, since 1970. Population suppression has been achieved and cotton protected by an integrated programme. In 1994, the programme was extended to the generally infested Imperial Valley (1994-1996 was in the pre-genetically engineered cotton era). In 1998, we extended the programme to the Blythe/Palo Verde Valley, California, USA. Plans include the addition of all southwestern cotton states, Arizona and New Mexico (USA) and Baja Norte and Sonora (Mexico) to the programme during the next five years.

Geographic display and analysis have been, and will continue to be, very important for data analysis and as decision implementation tools. The development of this entire system has been evolutionary. The programme has been well received by cotton producers in northern Mexico and southern California.

ACKNOWLEDGEMENTS

Our thanks to Amit Patel for computer engineering, GIS expertise, expertise on insect release operations, and forms development. Our deepest gratitude goes to David Pierce for ongoing support and vast knowledge in the areas of GIS, GPS, sterile insects, general equipment use and maintenance.

REFERENCES


SIT for Codling Moth Eradication in British Columbia, Canada

Kenneth A. Bloem¹ and Stephanie Bloem²

¹ OK-CM Sterile Insect Release Program, Box 1080, Osoyoos, BC, V0H 1V0, Canada
² USDA-ARS YARL, 5230 Konnowac Pass Rd., Wapato, WA 98951, USA

INTRODUCTION

The codling moth (CM), *Cydia pomonella* L. (Lepidoptera: Tortricidae), is considered the key pest of apples and pears in the fruit growing regions of south central British Columbia. This region includes about 18,000 acres of commercial production, as well as several urban centres with abundant backyard fruit trees and ornamental crab apples. Now, after 30 years of research and planning, an eradication programme using the sterile insect technique (SIT) has been implemented against CM. This article reviews the progress that the programme has made and how well reality has met expectations in key areas. Proverbs (1982) and Proverbs et al. (1982) reviewed the techniques for mass rearing, sterilising and releasing CM, DeBiasio (1988) developed the initial implementation plan and Dyck et al. (1993) reviewed the history and development of the programme up to 1992 when it became operational.

GEOGRAPHY AND TOPOGRAPHY

The fruit growing regions of southern British Columbia occur along isolated arid valleys that are surrounded by high mountains. The areas generally receive less than 300 mm of precipitation per year. Fruit is grown under irrigation and closely follows the lakes and rivers in the valley bottoms. The eradication programme encompasses all commercial apple and pear production in four such valleys, the Okanagan, Similkameen, Creston and Shuswap Valleys. The Okanagan Valley lies about 500 km east of Vancouver and the Pacific Coast. It runs north-south and extends into the state of Washington in the US, where it ties into the Columbia River system. The smaller adjacent Similkameen Valley extends west from the south end of the Okanagan Valley, and the Creston Valley is located about 200 km east of the Okanagan on the US/Canada border above the state of Idaho. The Shuswap Valley joins and extends the Okanagan Valley to the north. The topographical features of these valleys (steep mountain sides, arid terrain) and the fact that CM fly relatively short distances, particularly females, all help to isolate the area and reduce the risk of re-infestation once eradication is achieved.

The programme is currently operating in Zone 1, which includes the south Okanagan Valley from the US border near Osoyoos to Summerland, as well as the Similkameen and Creston Valleys. Zone 2 covers the area from Summerland north to Winfield and includes the largest urban centre, Kelowna. Zone 3 extends from Winfield north and east to Vernon and Salmon Arm.

CONSTRUCTION AND OPERATION OF THE REARING FACILITY

Capital funds in the amount of Cdn$7.7 million were approved by the federal and provincial governments for construction of the CM mass rearing facility and the purchase of operating equipment. Ground breaking began in January of 1992 in Osoyoos, BC, and construction was completed in March 1993. The project finished Cdn$300,000 under budget.

Although the reproductive colony was established and a small number of release trials were conducted in 1993, budget constraints did not permit full-scale testing of either rearing or release equipment until the first operating field season in 1994. Unfortunately, equipment failures soon became a chronic problem and threatened programme delivery. Some of the problems included undersized gear boxes for the diet pumps, micro-switches on diet lines that were not water or dust proof, insufficient cooling capacity to maintain proper rearing temperatures, humidity control problems, and unreliable electrical systems on the moth dispensing units.

Start-up problems are not uncommon for a facility of this type. Given that operational and equipment problems should be expected, it is critical to allow time for sufficient testing of all systems under actual operating conditions (while under warranty) and before demands for rearing and releasing become critical. This is particularly true when new and/or “improved” technologies are being introduced.

Despite these initial problems, the mass rearing facility has proved to be very well suited to rearing CM. From an initial production goal of 5.3 million CM per week (Dyck et al. 1993), actual production has increased from 8.7 million per week in 1994 to 14.2 million CM per week in 1997. This increase in production has largely been the result of improvements in process control, such as better humidity and temperature control, more uniform diet dispensing, and a more consistent and optimal number of eggs being placed on each tray of diet.

RELEASES

CM releases begin around 1 May and continue for 20 weeks until mid-September. Small 4-wheeled all-terrain vehicles (ATVs) outfitted with coolers on the back and moth dispensing units on the front, similar to those described in McMechan and Proverbs (1972), are used to release CM. Adult moths are packaged by volume into plastic petri dishes (700-900 per dish), sterilised with 25 krad of gamma radiation, loaded into coolers on the ATVs and transported to the field. Ice packs keep the CM chilled and inactive. When a driver is ready to release them, a petri dish is emptied into the hopper on the dispensing unit and chilled CM are gently blown under the trees as the ATV is driven up and down the orchard rows. Three or four passes are made through each acre of orchard. The programme releases sterile CM twice per week and the release rate varies with production levels. In 1994, the rate was ca. 450 moths per acre or 900 CM per acre per week. In 1997, increased production allowed for a release rate of ca. 750 moths per acre or 1,500 CM per acre per week.

The programme monitors the wild population, overflooding ratios and uniformity of releases on a weekly basis with wing-type pheromone traps baited with red rubber septa containing 1 mg codlemone, placed at a density of 1 per 2.5 acres during clean-up and 1 trap per 12.5 acres during active releases. A random examination of fruit is made yearly in approximately 600 or 1/3 of the orchards treated just prior to harvest to determine percent fruit damage by CM.
WILD POPULATION AND OVERFLOODING RATIOS

Overflooding ratios for a given species are calculated based on field experience and computer models that predict population rates of increase and/or decrease. Influencing factors determining overflooding ratios include the size of the wild population, the reproductive potential of the female, the potential impact of weather conditions, the quality and competitiveness of the sterile insects, cost constraints, and the time in which eradication is to be achieved. For CM, it was estimated that the release of enough sterile moths to provide an initial overflooding ratio of 40 sterile:1 wild would bring about eradication in 2-3 years.

Because most of these factors are difficult to measure with accuracy, calculations of production needs should err on the high side and calculations of production capabilities should be conservative. Miscalculations resulting in over-production may increase costs but should bring about eradication more quickly, whereas miscalculations on the low side may jeopardise a programme's success. Once a facility has been built and production capabilities established, the only recourse for dealing with low overflooding ratios is to decrease the size of the treatment area or combine releases with other control tactics to lower the wild population to a manageable level.

In 1992, the programme assumed that it would be possible to reduce the CM wild population to one that resulted in an average trap catch of less than two moths per trap in any given week. Taking into account trap density and efficiency, this number of CM was then multiplied by 40 in order to arrive at the production requirements for the facility. Unfortunately, when releases began in 1994, trap captures of wild CM reached 8 moths per trap per week during first generation. Although production estimates were conservative and output has steadily increased, the programme had to initially struggle with poor overflooding ratios, less than adequate control, and cost and timeline overruns.

INSECT QUALITY

Producing good quality insects is one of the most important components of a SIT programme (Huettel 1976). Rearing managers are continually pressured to reduce costs, improve efficiency and increase production numbers. Sterile to wild ratios, after all, are what drive SIT programmes. However, the requirement for success is not only to produce large numbers of sterile insects, but large numbers of insects that are competitive. Unfortunately, many steps in the rearing and release processes can have a negative impact on field performance and mating competitiveness (quality) of mass reared insects.

Insect quality issues should be addressed whenever possible during facility design. It is critical, therefore, that the engineering firm in charge of construction be flexible and willing to work alongside scientists so that new technologies are introduced and adapted to provide a better rearing environment, not rearing procedures adapted to fit an engineer's idea of "improvements" in the new facility. For example, the CM facility has a unique adult collection system where adults emerge directly into rearing rooms and are attracted by UV-lights attached to vacuum hoods mounted in the ceiling. This system only collects CM capable of flying to the UV/hoods and thus insures that good flight ability is selected for, and maintained in, the reproductive colony.

Two quality issues of concern to the CM programme have been the adverse effects of handling the moths prior to release and poor CM activity (relative to that of
wild CM) in cool weather. With respect to handling, we discovered that it is important to minimise the time that the CM are kept in cold storage. In 1994, turn-around time between adult collection and field release was 36-48 hours. In 1995, a third worker shift was implemented to irradiate CM immediately after collection. As a consequence, sterile CM are now no more than 12 hours old when released and field quality has improved significantly. It was also determined that bouncing of the petri dishes in the coolers on the ATVs had a negative impact on CM quality. A recommendation was made instructing release drivers to carry no more than half of their day’s supply of CM at any one time. With respect to poor competitiveness when CM are released in cool weather, we found that fluctuating the temperature during larval rearing only marginally increases adult flight activity in the field. Unpublished data by Judd at the AAFC-PARC, Summerland, BC, suggest that the problem may be more related to the way the CM are released (cool moths onto cool ground) than to the quality of the moths. We did find that mass reared CM that are induced into diapause (Bloem et al. 1997) and later released, perform significantly better in cool weather than CM reared under constant temperatures (Bloem et al. 1998). Other unpublished research also demonstrates that CM treated with lower doses of gamma radiation are significantly more competitive.

BYLAW ENFORCEMENT AND URBAN AREAS

Possibly, the greatest barrier to geographic eradication of CM in southern BC is the intimate interface between viable commercial orchards, abandoned orchards, hobby farms, and urban subdivisions. Unfortunately, all of the research for CM-SIT was conducted in, and developed for, areas of commercial production. However, urban areas, with relatively few host trees that are widely spaced and may harbour CM infestations of 50-100%, present a much different scenario. Under such conditions, it is difficult to imagine that the uniform distribution of sterile CM at standard orchard release rates would result in sufficiently high numbers of CM arriving at infested trees and bringing about any meaningful level of control. Releases in urban centres such as Penticton, BC, during 1994 bore this out.

In 1995, the programme adopted a policy of “zero tolerance” for CM infested fruit in all urban and non-commercial orchard properties. The preferred method for achieving “zero tolerance” is for property owners to remove all fruit from their trees before the end of the first or spring generation (during eradication years) or to remove the trees entirely. Incentive programmes were developed where those who strip their trees receive a discount on replacement fruit at packing houses and those who remove their trees receive a discount on replacement non-host trees at garden centres. Other methods of CM control such as removal of only infested fruit and the use of pesticide sprays are acceptable, but only if the same “zero tolerance” level is maintained throughout the season.

The programme employs 15 urban monitors to make inspections and enforce “zero tolerance” on roughly 5,000 properties in Zone 1, and 35 monitors to make inspections on over 12,000 properties in Zone 2. When a property is found to have any level of CM damage, it is issued with a control order for complete fruit removal. The failure to identify the requirements for urban clean-up in the implementation plan has been a major factor in the higher than anticipated costs for the programme. Since 1995, the programme has seen trap captures in the urban centres of Zone 1 drop from an average of 18 moths per trap per week to two moths per trap per week in 1997. However, strict enforcement of the programme’s zero tolerance policy remains a critical
and a controversial issue, and many doubt that the effort is aggressive enough to achieve eradication.

PUBLICITY

Eradication programmes cannot be conducted in an information vacuum. They require the active support and participation of various levels of government, the grower community and the general public. To effectively solicit and maintain this support requires an aggressive, ongoing communications campaign.

Probably the biggest failing of the programme in 1994 was insufficient communication with orchardists and homeowners. The insufficient pre-release publicity that was done left people with high expectations and little understanding of how SIT works. As a result, many orchardists stopped all control measures for CM, did not realise they had wild infestation levels that were much too high for SIT to control, and sustained damage well above the accepted economic injury level (0.5% at harvest).

In order to improve public awareness and perception of the programme, a communications firm was hired in 1995 and the budget for communications increased from Cdn$5,000 to $100,000 per year. The strategy was to inform the public of the importance of CM eradication and appeal to their sense of responsibility, not unlike campaigns for community recycling programmes. Commercial growers now receive direct mail four times a year updating them on the progress of the programme. In addition, they are reminded of compliance and spray requirements through regular news releases, radio announcements, the Ministry of Agriculture’s information network, and weekly programme updates that are available through packing houses and local fieldmen. Urban and non-commercial property owners also receive direct mail stressing the “zero tolerance” policy and compliance dates. Other methods used to inform the public include extensive radio and newspaper advertising, presentations about CM-SIT to school and community groups, and information booths at shopping malls, garden centres and agricultural fairs.

FIELD PROGRESS IN ZONE 1

Releases of sterile CM began in 1994. Unfortunately, the wild population was still unacceptably high (trap captures of wild CM reached an average of eight moths per trap per week during peak spring emergence) and expectations of success were equally unrealistic. As the year developed, start-up problems, poor communication with growers, high temperatures, heavy crop losses due to hail damage, and low fruit and juice prices combined to produce high CM damage and a large overwintering population at the end of the season.

Things began to change in 1995 when growers were convinced to combine an aggressive spray programme with the release of sterile CM. Since then, the resulting decline in the wild CM population has been dramatic (Figure 1). The average trap catch has been reduced from 13 CM per trap per week during peak first generation and 2.5 moths during peak second generation to an average of 1.2 and <0.5 moths per trap per week for first and second brood, respectively, in 1997. The desired 40 sterile:1 wild overflooding ratio was achieved in all but two weeks in the spring and it was greater than 500:1 throughout the last half of the season in 1997. The majority of growers applied only one cover spray for CM in 1997, essentially no damage was reported, and
it is likely that many growers will not be required to spray for CM in the south Okanagan in future years.

Figure 1. Sterile Insect Release Program field results for 1995–1997, including average trap captures, overflooding ratios and apple damage at harvest.
CURRENT TIMELINE

The Sterile Insect Release (SIR) Mandate Area has now been divided into three (rather than two) treatment zones, the south (Zone 1), central (Zone 2) and north (Zone 3) Okanagan, with approximately 8,500, 6,250 and 3,250 acres of commercial apple and pear production, respectively (SIR Programme Strategic Plan 1996). Each zone will undergo three years of pre-release sanitation using conventional methods to lower the wild population and eliminate wild trees and derelict orchards. This will be followed by three years of CM releases to achieve eradication. Eradication in Zone 1 is anticipated by the end of 1999. The clean-up phase for Zone 2 began in 1997, with releases scheduled to begin in 2000 and eradication anticipated by the end of 2002. Eradication in Zone 3 is anticipated by 2005.

BUDGET

Federal and provincial governments paid the initial capital costs (Cdn$7.4 million), while the five municipal governments agreed to levy a CM-SIT parcel tax on commercial apple and pear growers and a mil rate tax on property owners to fund the yearly operating costs of the programme. According to the implementation plan, operating costs were projected to be Cdn$2.0-2.5 million per year for eight years (1992-1999). It was proposed that growers would pay Cdn$40 per acre of apples and pears (roughly the yearly cost of CM control for an average grower based on 2.5 applications of azinphosmethyl at 1.4 kg/2.5 acres). The mil rate tax on property owners would vary between Cdn$0.13 – Cdn$0.26 per Cdn$1,000 of property value or about Cdn$6.00 per household.

It soon became obvious, however, that the programme had significantly underestimated the effort and costs involved, particularly to deliver the programme to urban areas and to remove wild trees and derelict orchards (SIR Programme Strategic Plan 1996). As a result, payment for growers in Zone 1 increased to Cdn$70 per acre in 1994, Cdn$72.10 in 1995, Cdn$74.26 in 1996 and Cdn$80.00 in 1997. Although property owners were only being charged Cdn$0.15-0.20 per Cdn$1,000 of assessed land value, municipal government representatives argued that because property values had increased they were actually paying more than double (Cdn$12-15 per household) what they had originally agreed to. After an intense lobby effort by the programme’s governing board in 1997, the federal and provincial governments agreed to each contribute an additional Cdn$2 million to stabilise the annual cost of the programme to growers at Cdn$80 per acre of apples and pears and to homeowners at Cdn$0.195 per Cdn$1,000 of assessed land value. In 1997, the total operating budget was Cdn$3.2 million. The operating budget for 1998 is Cdn$3.7 million.

CONCLUSION

The SIR programme has faced many challenges since its inception and it continues to struggle with the concept of eradication (vs. area-wide control) and the associated long-term financial, political and operational demands. Despite this, the SIR programme has been making steady progress for the past three years and each year, more of the end users are satisfied with the results. This is evidenced by: the additional funds contributed by the federal and provincial governments in 1997, the willingness of
growers to pay higher than expected yearly programme costs, and the cooperation by homeowners who not only remove the fruit or the host trees from their properties but also help the programme to find CM infestations in the surrounding neighbourhoods. As conventional pest control methods become more expensive, less effective and less tolerated, it is hoped that export of the technology for CM-SIT will be possible to other apple growing areas around the world.

REFERENCES


Area-Wide Population Suppression of Codling Moth

C.O. Calkins¹, A.L. Knight¹, G. Richardson² and K.A. Bloem³

¹ USDA, Agricultural Research Service, Yakima Agricultural Research Laboratory, Wapato, Washington, WA 98951 USA
² USDA, ARS, Yakima Agricultural Research Laboratory, Oroville, Washington, USA
³ USDA, APHIS, PPQ, Central Biological Control at Florida, A&M University, Tallahassee, Florida, USA

INTRODUCTION

The area-wide pest population control concept began with E.F. Knipling (1979) in the 1970s. Control of a pest population on individual fields does little to control the overall pest population because only a portion of the population is being affected. Expanding control tactics beyond individual farms tends to suppress the population on a wider scale and frequently results in suppression of the population for more than one year. The Agriculture Research Service (ARS) believes that this concept has not been addressed with the focus and support that it deserves. The ARS Administration made a conscious decision in 1994 to create a series of area-wide programmes funded out of ARS-based funds that had previously been used for pilot tests. These programmes involve a coordinated effort among ARS and university scientists, growers, and fieldmen for agriculture supply centres and fruit packing houses.

The first area-wide programme supported by ARS was the codling moth (CM), Cydia pomonella L. (Lepidoptera: Tortricidae) suppression programme. The codling moth is the key pest of pome fruit throughout the western United States (Beers et al. 1993). About half of the insecticides applied on these crops are directed toward this pest. A non-insecticidal control technique, mating disruption (MD), is available to replace the organophosphates. Removal of the hard pesticides directed against this pest would do the most to allow natural enemies to survive and reproduce in the orchards, which in turn would have the effect of reducing secondary pests. Elimination of the pesticides would also remove much of the health risks to workers and would minimise buildup of pesticide resistance.

The objectives of the Codling Moth Area-wide Program are to enhance the efficacy of the non-pesticide approach, to demonstrate that mating disruption will work if conducted properly, to develop biological technology to lower costs of control that complement mating disruption, to implement effective biological control systems, to improve monitoring systems for all pests and their principal natural enemies, to improve worker safety and to improve the perception that fruit production is safe for consumers, especially for children and infants.

INITIATION OF THE AREA-WIDE PROGRAMME

Prior to the inception of this programme, several large growers in Washington were using mating disruption for the codling moth routinely and getting satisfactory control. However, small growers seemed to have frequent failures. They and others
concluded that the main problem was from neighbouring orchards that, by not using the technique, were a source of mated females that were flying into their MD orchards. Other complaints were that control could not be maintained on hilly topography, on orchard perimeters, and near bin, prop and brush piles. The complaints from growers, who had tried the technique and failed, discouraged others from using it. The problem at the outset was to convince growers to try the idea of creating large contiguous blocks under the same management strategy by joining together and coordinating the timing of applying mating disruption dispensers and cover sprays.

To participate in the area-wide programme, certain criteria were required. These were: 1) the production area and cultural practices should be typical of good fruit growing areas, 2) populations of key pests should occur consistently so that meaningful data could be collected to measure the effects of reduced pesticide use, 3) producers within the test areas should be willing to cooperate and share costs, and 4) the test area should have the organisational structure to support and establish the enhanced integrated pest management (IPM) systems in the local community.

The initial task was to set up the test areas for the pilot projects. The sites selected were: one in California, one in Oregon and three in Washington. These sites, referred to as the Codling Moth Area-wide Management Project (CAMP), were composed of apple and pear orchards owned by interested growers whose properties were fairly contiguous. To ensure that participating growers would remain in the programme, a partial subsidy of US$125 per hectare was granted to each participant for three years. There was no subsidy during the last two years of the programme. The initial effort was for the growers to install 1,000 pheromone dispensers per hectare in the upper one-third of the tree canopy. The typical orchard in the Pacific Northwest has about 500 trees per hectare, thus two dispensers per tree were most commonly recommended. Because mating disruption is most efficient at low moth populations (Beers et al. 1993, Vickers and Rothschild 1991), the growers were also encouraged to apply at least one cover spray of azinphosmethyl to lower the initial codling moth population. Cover sprays of azinphosmethyl are recommended at 250 degree days after biofix, about 15 days before peak codling moth egg hatch occurs. Biofix is the date when the first consistent emergence of codling moths are detected in the spring. This usually happens just before “Red Delicious” trees bloom. Traps baited with 10 mg codlemone lures were placed throughout the blocks at the rate of one trap per hectare shortly after biofix to monitor the population. A threshold of five moths per trap per generation was established for deciding whether to apply sprays for the second generation.

The amount of fruit damaged by the codling moth was assessed through fruit examinations during the larval phase of the first generation and at harvest. Traps were also maintained for leafrollers and constant monitoring for other secondary pests was conducted. Other types of monitoring consisted of determining percentages of parasitism of leafhoppers, leafminers, and aphids in the individual orchards.

MATING DISRUPTION AND THE STERILE INSECT TECHNIQUE

One of the CAMP sites, Lake Osoyoos, consisted of about 180 hectares on the east and west sides of Lake Osoyoos near the town of Oroville and abutting the Canadian border to the north. A codling moth eradication programme using the sterile insect technique (SIT) is being conducted immediately north of the border in Canada. The codling moth sterile insect release programme (SIR) was started in 1992 to
eradicate this pest from 7,500 ha of orchards in south central British Columbia (Dyck et al. 1993). A modern rearing facility costing US$5 million was constructed just outside the town of Osoyoos, British Columbia. In 1997, it produced an average of 14 million sterile codling moths per week. The first sterile moths were released in 1994, and the programme initially encountered major problems due to the unexpectedly high levels of wild codling moths present in many orchards. In 1995, growers were required to supplement the SIR programme with multiple applications of organophosphate insecticides (OP). However since 1995, the number of sprays has been steadily decreasing and control has been improving. The SIR programme was deemed successful in 1997. As most growers applied less than one OP spray per season, the catch of wild moths averaged < 2 per trap per season, the sterile:fertile moth ratio in traps soared to 297:1, and 91% of the orchards had no discernible codling moth fruit injury at harvest (Bloem and Bloem 2000).

Adjacent pome fruit orchards are present south of the Canadian-US border along both sides of Lake Osoyoos. The Canadian SIR programme envisioned creating a moth-free buffer within the US to minimise continual reintroductions into Canada. Through close cooperation with the SIR Board, ARS organised a similar SIR programme in 1995 for 160 ha of orchards extending 1 km into the US. The initial Lake Osoyoos CAMP site included 14 growers farming 64 orchards (91% apples, 5% pears, and 4% cherries). One grower did not participate during the first two years of the study and his orchards remained a major source of wild moths during those years. All other apple and pear orchards were treated with 1,000-ISOMATE-C+ dispensers per hectare for mating disruption of codling moths. In addition, orchards were treated with cover sprays of insecticides as needed for the codling moths and leafrollers.

Sterile codling moths were provided by the Canadian SIR programme. During the first two years of the project, moths were released only during the second generation flight period from 1 July to 15 September. During 1997, chilled moths were released twice weekly at the rate of 1,120 moths per hectare during both flight periods from 1 May to 15 September. Releases were made from all-terrain vehicles using a special moth release blower device mounted on the front of the vehicles (McMeacha and Proverbs 1972). Moths were released along prescribed transects spaced 30 m apart through all of the MD orchards. The cost of the programme, including labour and equipment, has been ca. Cdn$38 per hectare but does not include the cost of moths or trap monitoring. Canadian growers are charged Cdn$150 per hectare but the programme is also supported by taxes on homeowners. The full cost of the SIR programme is estimated to be nearly Cdn$500 per hectare.

All orchards were monitored with sex pheromone-baited traps (10 mg lures) at a density of 1 trap per hectare. Two species of leafrollers, oblique-banded, *Choristoneura rosaceana* Harris, and pandemis, *Pandemis pyrusana* Kearfott, were monitored with sex pheromone-baited traps at a density of one per 4 hectares. All orchards were routinely scouted to visually assess pest and natural enemy populations. Ten orchards were extensively sampled for all the major pests and their natural enemies during the season. Six to eight orchards treated with conventional pesticides outside the project served as controls and were monitored similarly each year to provide an evaluation of the programme’s impact.

Baseline data on pest populations from this site were collected from ca. 80 hectares in 1994 prior to the start of the area-wide project. Growers were applying an average of 5.5 sprays of azinphosmethyl to control the codling moth. Traps loaded with 1 mg lures caught an average of 60 fertile and 14 sterile Canadian moths during that season. These sterile moths were released on the Canadian side of the border. Fruit
injury from the codling moths averaged 0.3%, but ranged from 0.05 to 3.0% among the orchards. Fruit injury by leafrollers averaged 1.1%. Surprisingly, growers were unaware of the presence of leafrollers and this fruit injury had been previously misidentified as codling moth damage in the packing houses.

The results of the Lake Osoyoos CAMP project have been evaluated both in terms of the baseline data and by comparison with the conventional programmes used by the growers outside the project. Since 1994, the growers in the project have reduced their use of broad spectrum organophosphate insecticides from 5.5 to 0.2 sprays per season. Fruit injury due to codling moths has fallen from 0.30% to 0.06%. Growers in the project have had 70% less injury than those outside the project during these three years. During 1995 and 1996, growers in the project used 70% less organophosphate insecticides than growers outside the project. Then in 1997, growers at the Lake Osoyoos CAMP site nearly eliminated the use of these insecticides (Table 1).

Table 1. Summary of results for codling moth from the Lake Osoyoos CAMP, during the baseline year (1994) and the first three years, 1995—97.

<table>
<thead>
<tr>
<th>Year</th>
<th>% CM injury</th>
<th>Mean wild moth catch/trap/season</th>
<th>OP applications per season</th>
<th>Sterile/Fertile moth ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0.30</td>
<td>60.0</td>
<td>5.5</td>
<td>0.3:1</td>
</tr>
<tr>
<td>1995</td>
<td>0.22</td>
<td>4.29</td>
<td>2.2</td>
<td>31:1</td>
</tr>
<tr>
<td>1996</td>
<td>0.04</td>
<td>0.82</td>
<td>1.8</td>
<td>181:1</td>
</tr>
<tr>
<td>1997</td>
<td>0.06</td>
<td>0.31</td>
<td>0.2</td>
<td>369:1</td>
</tr>
</tbody>
</table>

Leafrollers have been a major concern of growers during the three years of the programme. Control was not improved in the first year when compared with the baseline data and was somewhat higher than in the outside orchards (1.0% vs. 0.75%). During the last two years, however, fruit injury by leafrollers has been 70% lower within versus outside the project (0.36% vs. 1.0%). Leafrollers inside the project have been managed by an increase in the use of *Bacillus thuringiensis* insecticides.

Other secondary pests have not been a major concern during the three years of this project and few additional insecticidal sprays have been applied. During 1997, injury from true bugs (Hemiptera: Heteroptera) averaged 0.21% inside versus 0.48% in the comparison blocks. Cutworm (Lepidoptera: Noctuidae) injury was somewhat higher in the project than outside (0.8 vs. 0.04%).

ARS will terminate their role in the area-wide programme on 30 September 1999. This programme was never intended to be a perpetual government programme; rather it was designed as a self-help programme whereby ARS would demonstrate the strategy and effectiveness of mating disruption and SIT for small growers. The growers are expected to continue the coordinated programme on their own and from all indications, it appears that this is the case with the Lake Osoyoos programme.
REFERENCES


Use of Nuclear Techniques in Biological Control

Patrick D. Greany¹ and James E. Carpenter²

¹ Center for Medical, Agricultural and Veterinary Entomology, ARS-USDA, Gainesville, FL, USA
² Insect Biology and Population Management Research Laboratory, ARS-USDA, Tifton, GA, USA

INTRODUCTION

As pointed out by Benbrook (1996), pest management is at a crossroads, and there is a great need for new, biointensive pest management strategies. Among these approaches, biological control is a keystone. However, because of increasing concerns about the introduction of exotic natural enemies of insect pests and weeds (Howarth 1991, Delfosse 1997), the overall thrust of biological control has moved toward augmentative biological control, involving releases of established natural enemy species (Knipling 1992). This in turn has created a need to develop more cost-effective mass rearing technologies for beneficial insects. Nuclear techniques could play an especially important role in augmentative biological control, not only in facilitating mass rearing, but in several other ways, as indicated below.

Recognising the potential value for use of nuclear techniques in biological control, the Insect and Pest Control Section of the Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture, International Atomic Energy Agency, sponsored a Consultants’ Group Meeting on this subject in April 1997. The Group produced a document entitled Use of Nuclear Techniques in Biological Control: Managing Pests, Facilitating Trade and Protecting the Environment. The consultants included the authors of this paper as well as Ernest Delfosse (at that time, with the USDA-APHIS National Biological Control Institute), Garry Hill (Intl. Institute for Biological Control), Sinthya Penn (Beneficial Insectary), and Felipe Jeronimo (USDA-APHIS PPQ, Guatemala). The remarks presented in this paper reflect the thoughts presented by these consultants and other participants at the IAEA-sponsored meeting.

Several potential uses for nuclear techniques were identified by the Consultants’ Group, including: 1) improvements in rearing media (either artificial diets or natural hosts/prey), 2) provision of sterilised natural prey to be used as food during shipment, to ameliorate concerns relating to the incidental presence of hitchhiking pests, 3) provision of supplemental food or hosts in the field, to increase the initial survival and buildup of released natural enemies, and 4) reproductive sterilisation of weed-feeding insects that are candidates for biological control, for use in open field trials.

APPLICATIONS OF IONISING RADIATION

Ionising radiation offers a reliable means to achieve: 1) developmental arrest of hosts/prey for use in in vivo rearing, 2) microbial pasteurisation or sterilisation of artificial media and possibly even natural hosts/prey (e.g., to kill Nosema spp.), and

3) reproductive sterilisation of hosts/prey to prevent release of viable pests along with beneficial insects.

**Developmental Arrest**

Gamma radiation has been used to inhibit development of Caribbean fruit flies, *Anastrepha suspensa* Loew, that escape parasitisation by *Diachasmimorpha longicaudata* (Ashmead) (Sivinski and Smittle 1990). This was done to preclude the inadvertent release of fertile adult fruit flies along with parasitoids in inoculative and inundative release programmes in Florida. In this case, the fruit fly larvae were irradiated using ca. 4 kR (40 Gy) during the third instar, prior to exposure to parasitoids. This was a more useful application of gamma radiation than that of Ramadan and Wong (1989), who exposed pupae of the Oriental fruit fly, *Bactrocera (Dacus) dorsalis* (Hendel) to gamma radiation after having already exposed the larvae to parasitisation by *Diachasmimorpha (Biosteres) longicaudata*, resulting in sterility of the adult parasitoids. In the studies of Sivinski and Smittle, the dose of gamma radiation (from a Cesium source) prevented adult eclosion of non-parasitised caribflies, but it did not prevent these larvae from serving as viable hosts for *D. longicaudata*. This allowed the investigators to safely set out puparia from larvae exposed to parasitoids without fear of releasing fertile flies into the area. Their work paralleled the earlier studies of Morgan et al. (1986), who used gamma radiation (50 kR or 500 Gy) to inhibit development of pupae of *Musca domestica* L. that were then used as hosts for the parasitoid *Spalangia endius* Walker. Similar benefits were obtained by Roth et al. (1991), who used irradiated horn fly pupae as hosts for hymenopterous parasitoids. Morgan et al. (1986) also found that irradiated housefly pupae could be used successfully for an extended period (ca. 10 weeks) prior to parasitisation by storing them at a low temperature (4.4°C), as long as adequate humidity was maintained.

Another application for ionising radiation that has promise is to inhibit the cellular and/or humoral defense reactions of host insects that might otherwise serve as optimal factitious hosts for beneficial insects. This approach was tested as a means of inhibiting encapsulation of the parasitoid *Microplitis croceipes* Cresson in a candidate factitious host, *Galleria mellonella* L. (S. Ferkovich, personal communication). This parasitoid usually attacks larvae of *Heliothis* and *Helicoverpa* spp., but it will oviposit into *Galleria* larvae, and ca. 20% routinely escape encapsulation and complete development in this laboratory host, although the *Microplitis* adults derived from *Galleria* larvae were considerably smaller than those reared in *Heliothis/Helicoverpa* larvae (Gupta et al. 1996). It was felt that by using gamma radiation, it might be possible to substitute *Galleria* larvae for *Heliothis/Helicoverpa* larvae and thereby economise considerably in the rearing of *Microplitis*. Unfortunately, at no radiation dose (up to 100 Gy) was it possible to achieve an increase in success in the use of *Galleria* (S. Ferkovich, personal communication). Although this approach was not successful in this instance, the principle should be kept in mind for other host-parasitoid systems, to enable more economical in vivo rearing.

An untested, but promising, application for gamma radiation is to inhibit the behavioural resistance of hosts/prey, so that they can be made more suitable for attack by parasitoids and/or predators that may otherwise be injured by their hosts. Similarly, it may be possible to prevent other behaviours that diminish the suitability of candidate hosts/prey, such as bothersome web spinning by *G. mellonella* larvae.
An excellent application for ionising radiation is for use in microbial pasteurisation and sterilisation of artificial media and even natural hosts/prey for rearing parasitoids and predators. Gamma radiation, as well as X-rays, provides a means of killing bacteria, fungi, viruses, and protozoa that may impair growth and development of insect parasitoids and predators without nutritional damage to the artificial media, and it can be used to dramatically increase the medium’s shelf life upon storage. Irradiation is ideally suited for use in insect rearing for several reasons. First, it is easy to achieve repeatable doses. Second, there is no thermal degradation of the diet components, in contrast to the use of steam or dry heat sterilisation, which changes the physical properties of media due to denaturation of proteins, for example. In addition, thermolabile enveloping membranes and diet packaging films such as Parafilm®, are generally unaffected by gamma radiation and X-rays at the rates used for these purposes. Ionising radiation can also be easily employed to sterilise materials that cannot be filter sterilised, such as thick, viscous media with numerous particles present. One of the greatest virtues of this approach is that it can be used to sterilise media after packaging (described as “terminal sterilisation” in the pharmaceutical industry). This helps ensure long shelf life during storage, and helps prevent rapid microbial contamination of media when presented to beneficial insects.

As recently as 1984, little success had been made in the development of artificial media for entomophagous insects (King and Leppla 1984). However, in the past ten years or so, great advances have been made in developing artificial media that are suitable for a myriad of insect natural enemies (see Anderson and Leppla 1992, Grenier et al. 1994 and references therein). In many of these instances, it probably would have been extremely helpful to use ionising radiation to improve the rearing success on artificial media. This approach has been of great value in our own studies on a variety of predators and ectoparasitoids that we are rearing on an artificial medium (“DI-Diet”) free of any insect components (Greany and Carpenter 1996, Carpenter and Greany 1998). Our approach is to prepare the medium under clean (but not sterile) conditions, and then to encapsulate it before subjecting the final product to gamma radiation, using a dose of ca. 1.7 kGy. This achieves a high degree of microbial control which, along with storage at 4°C, allows the product to be kept for at least several weeks. Use of this system is illustrated in Figure 1, showing feeding of Podisus maculiventris nymphs upon our medium encapsulated in Parafilm.

We are currently working jointly with a scientific and engineering research firm (Analytical Research Systems, Inc., of Gainesville, FL) to develop a sophisticated encapsulation process for our medium which will also include sterilisation by gamma radiation. This combination of high volume diet packaging and sterilisation should significantly reduce the cost of rearing a variety of beneficial insects and simultaneously improve the success of the use of the artificial medium. The approach may be very useful to complement the excellent artificial diet and rearing system developed by Rojas et al. (1996) for the boll weevil parasitoid, Catolaccus grandis. It also provides a novel means for presenting control agents such as pathogenic microorganisms to insect pests, for example, fire ants (the response of fire ants to diet-filled, polymer-coated capsules is illustrated in Figure 2).

Finally, it may also be possible to use ionising radiation to kill disease organisms such as the microsporidian Nosema spp. that are often present in host organisms intended for parasitoid/predator rearing, and which can be transmitted from infected
hosts to their natural enemies. For example, Undeen et al. (1984) showed that spores of *Nosema algerae* could be killed by gamma radiation in excess of 3 kR (30 Gy).

**Figure 1.** Fourth instar nymphs of *Podisus maculiventris* feeding on “DI-diet” encapsulated in Parafilm, and irradiated after encapsulation using gamma radiation.

**Figure 2.** Imported fire ants investigating diet-filled capsules prior to consuming contents.

**Reproductive Sterilisation**

Gamma radiation has been used to cause inherited sterility among progeny of radiation-exposed insects (i.e., F₁ sterility), so that these reproductively incompetent insects can be safely field-released for use as hosts/prey for indigenous natural enemies. This subject will be covered in detail by J. Carpenter elsewhere, and therefore will not be described further here.

Use of ionising radiation for reproductive sterilisation could be a great assistance in providing the safe international shipment of biological control organisms by equipping these organisms with natural prey that had been reproductively sterilised prior to packaging. For example, it would allow shipment of predaceous phytoseiid...
mites with prey mites (for use as food during shipment) without fear that the spider mites could become a problem upon release of the predatory mites.

Another promising application of ionising radiation would be to allow testing of agents intended for weed control outside quarantine conditions if these agents are first sterilised reproductively. This could enable them to be released into the field to determine whether they will feed upon the target weed and any other non-target plants without fear that they could become established and perhaps cause inadvertent harm.

IMPLEMENTATION OF IONISING RADIATION IN BIOLOGICAL CONTROL

Considering the demonstrated benefits associated with the use of nuclear techniques for these purposes, it is logical to ask, “Why isn’t this approach being used to greater advantage?” One of the reasons is the relative scarcity of irradiators, but it is, in part, due to fear of irradiation and a lack of understanding of the effects of this process. While a number of USDA-ARS, APHIS and university laboratories have a gamma radiation source readily available, relatively little use has been made of these facilities for purposes relating to rearing beneficial insects. Commercial firms have had even less opportunity to avail themselves of this promising technology because of difficulty in obtaining access to irradiators.

Some persons mistakenly fear that the use of a radioactive source, or even a linear accelerator or X-ray machine, will cause the exposed materials to become radioactive. Another common misconception is that this process will destroy the nutritional value of the irradiated materials, or will cause the formation of an abundance of free radicals of oxygen or other radiolytic products that will render the foodstuff toxic. The comfort level of potential users might be increased through an educational programme to enlighten them about the safety of this technology; an excellent booklet on this topic was published by the IAEA (Anonymous 1995).

One of the genuine “hassles” that inhibits potential users from taking better advantage of this technology is the abundance of regulatory agency requirements that must be met for acquisition and maintenance of a radioactive source, such as a Cesium or Cobalt source. Along with this, there is a high initial cost for purchase of even a small (ca. 0.5 litre volume) gammacell (in the order of US$100,000). The need to ultimately dispose of the radioactive waste also constitutes at least a minor problem. Fortunately, X-ray machines and linear accelerators for use in food irradiation are being developed. These devices are subject to fewer regulatory constraints than $^{137}$Cesium or $^{60}$Cobalt sources, and they may prove much more user-friendly for the insect rearing community. Relatively low-cost cabinet X-ray machines are being developed that will suffice for many small-scale users.

SUMMARY

Overall, there is great promise for the use of ionising radiation in support of the development of improved mass rearing methods to be used for augmentative biological control. The advent of more and more artificial media that are proving suitable for numerous beneficial insects is providing an impetus for development of appropriate sterilisation regimes. Similarly, ionising radiation may also be used to great advantage to improve conventional in vivo rearing strategies for many parasitoids and predators.
Finally, the regulatory climate is becoming much more stringent, and radiation techniques may help facilitate international, interstate, and even intrastate shipments of insect natural enemies, by preventing the accidental release of reproductively viable pest organisms along with their natural enemies (Delfosse 1997, Hill 1997), and it could enable improved testing of agents intended to be used for biological control of weeds prior to field release by first releasing reproductively-sterilised individuals for field trials.

REFERENCES


Biological Control Against the Carob Moth *Ectomyelois ceratoniae* in Oases and in Packing Houses in Tunisia


1 Institut National Agronomique de Tunisie, 43 Avenue Charles Nicolle cité Mahrajène, 1082 Tunis Mahrajène, Tunisia
2 INRA Versaille France
3 Groupement Interprofessionnel de Dattes de Toseur, Tunisia

**INTRODUCTION**

The carob moth, *Ectomyelois ceratoniae* Zeller is abundant in the Mediterranean countries. It attacks various dry fruit in cultures or in stored products, notably pomegranate, *Punica granatum* L.; date palm, *Phoenix dactylifera* L. plantations; citrus, *Citrus* spp., apricot, *Prunus armeniaca* L. and pistachios, *Pistachio vera*. We can find *E. ceratoniae* in the north as well as in the south of Tunisia, especially in central zones and Saharan areas where caterpillar infestations can reach 90% of pomegranate fruit and 20% of dates (Dhouibi 1991). To reduce this damage, several control methods have been experimented. Chemical control is the most effective means of control against pests. However, against this species, insecticides seem to be difficult and randomly used, due to the endophytic behaviour of the pyralid and the position of the fruit on the pomegranate tree. Moreover, this method has very ominous repercussions on biological cadence. Besides, it is necessary to look for other control means to allow the preservation of the ecosystem. In Tunisia, several efforts have been directed at biological control, by using local parasitoids and through usage of the bio-insecticides mainly *Bacillus thuringiensis* (Dhouibi 1992, 1994, Dhouibi and Jemmasi 1993). In order to substitute the chemical control and to strengthen the integrated control, other possibilities can be envisaged, for example, the genetic method or the autocidal control, that is, based on mass rearing and the substerile male releases into the natural population. For the purpose, it provokes the sterility to ulterior generations and evaluates the impact of irradiation on the different biological parameters of emerged adults from treated nymphs and their competitiveness. Dhouibi and Omran (1995) and Dhouibi and Tijani (1996) have studied the mass rearing of the carob moth pyralid on an artificial diet and the effect of different irradiation doses, especially a substerilising dose, on *E. ceratoniae* pupae.

**MATERIALS AND METHODS**

Since 1982, research has been undertaken to study the possibility of integrated control against date pyralids by the judicious combined use of all possible control methods. For this purpose we have realised the following: