CHAPTER 7.1.

IMPACT OF SCREWWORM ERADICATION PROGRAMMES USING THE STERILE INSECT TECHNIQUE

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SUMMARY

The use of the sterile insect technique (SIT) in New World screwworm *Cochliomyia hominivorax* (Coquerel) eradication programmes has been successfully demonstrated. As a result of a 45-year area-wide campaign, suppression and eradication have been achieved in the USA, Mexico, Belize, Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, Panama north of the Canal, some Caribbean Islands, and the outbreak in Libya, North Africa. The humans, livestock, and wildlife in these countries are now free of this dangerous pest. It has been estimated that the annual producer benefits are: USA - USD 796 million, México - USD 292 million, and Central America - USD 77.9 million. In Libya, the estimated benefit/cost ratio was 5:1 in the infested zone, and 10:1 in the whole country. If the New World screwworm were eradicated in South America, it has been estimated that each year USD 3592 million could be saved. Small field trials have confirmed that the SIT would be effective for the area-wide control of the Old World screwworm *Chrysomya bezziana* (Villeneuve).

1. INTRODUCTION

The application of the sterile insect technique (SIT), as part of an area-wide integrated pest management (AW-IPM) approach for the suppression and eradication of the New World screwworm *Cochliomyia hominivorax* (Coquerel), has been comprehensively demonstrated (Klassen and Curtis, this volume). The similar biology of the New World screwworm and the Old World screwworm *Chrysomya bezziana* (Villeneuve) indicates that the SIT should also be effective against the Old World screwworm. Field trials in Papua New Guinea provided strong indications that the SIT would be effective in suppressing the Old World screwworm (Spradbery 1990, Spradbery et al. 1989), but were not conclusive, although more recent studies in Malaysia have provided validation of the SIT for this screwworm species (R. J. Mahon, unpublished data).

Today, animal production is a high priority in world agriculture. There is an increasing demand for meat, dairy and egg production — major sources of animal protein for the world's growing population. To satisfy this demand, a diversity of livestock production systems is found in the different continents, including keeping cattie, buffaloes, sheep, goats, hogs, and poultry on traditional smallholder farms, and in extensive grazing or in more intensive systems, depending on the local circumstances.

In developing countries, animal production makes a major contribution to local and national food supplies. This production provides food security, cash income to a large number of rural people, and benefits to the whole economy. Commercial livestock-keeping increases total farm produce and income, provides year-round employment, and reduces the investment risk of raising livestock. Income from livestock produces provides funds to purchase additional means to improve crops, or for other farm investment. Livestock production enhances the economic viability and sustainability of the farming system (FAO 1992).

Predictions made by the International Food Policy Research Institute (IFPRI), International Livestock Research Institute (ILR1), and Food and Agriculture Organization of the United Nations (FAO), suggest that, between 1993 and 2020, total world meat consumption will double from 180 to 300 million tonnes, and milk production will increase from 400 to 650 million tonnes (Delgado et al. 1999). To satisfy this growing demand, the world must find mechanisms to develop greater production efficiencies without damaging the already stressed environment. Part of this productivity increase can be realized through improvements in animal health.

Animal diseases affect the livestock sector directly through mortality, reduced fertility, and loss of weight, and together with other factors have chronic debilitating effects on livestock and their production. This results in inefficient utilization of scarce resources. Both ectoparasitic and endoparasitic diseases are recognized as major factors limiting production. The cumulative effect of parasitic diseases is perhaps a greater cause of economic losses than that of any other disease.

Myiasis is caused by an infestation of a living vertebrate's tissue or fluids by larvae (maggots) of flies (Díptera). Even minor infestations cause annoyance to animals, disrupting normal habits including feeding and resting. In some situations there is loss of milk, meat or wool production, or in the value of hides.

There are at least 20 species of flies responsible for myiasis, feeding specifically on living animal tissues to complete the larval stage of the life cycle (James 1947).

Two of the most important obligatory parasitic myiasis flies are the New World screwworm and the Old World screwworm.

In the Western Hemisphere's tropical and subtropical regions, the New World screwworm is one of the most damaging insect parasites of livestock. It alone represents economic losses each year of hundreds of millions of dollars (USD) (section 2.3.). Losses result not only from direct reduction in productivity due to sickness and death, but also from the labour and insecticide costs incurred by continuously having to inspect and treat wounds. In endemic areas the annual cost of controlling New World screwworm myiasis in domestic animals was estimated at USD 4.82-10.71 per head (Rawlins 1985). These flesh-eating larvae also represent a serious human-health problem (Reichard et al. 1992, Vargas-Terán 2002a, Wyss 2002a).

Gravid female flies are attracted to wounds, even those as small as a tick bite. Eggs are laid in, and around the border of, such wounds. After the eggs hatch, the larvae begin feeding on the live body tissue. As the maggots feed, they enlarge the wound, making it attractive for other female flies to oviposit and also susceptible to secondary infection. Without treatment, it is common for the animal to die.

The New World screwworm has a high reproductive rate. Each female can lay several clutches of up to 400 eggs each. Under optimum conditions, a generation or life cycle can be as short as 3 weeks. Before suppression and eradication programmes commenced, the New World screwworm occurred naturally in the south-western USA, Central America, the Caribbean, and tropical and subtropical South America. By accident, through animal movement, it spread to the south-eastern USA, where it became established (FAO 1989).

The life cycles of the Old World and New World screwworms are very similar, lasting about 21 days, and these species are a good example of co-evolution. However the Old World screwworm is smaller than the New World screwworm, and the females are less fecund, producing egg clutches of 190-250 eggs. The Old World screwworm causes myiases in Africa, Arabia, the Persian Gulf (Bahrain, Iraq, Iran), India, and South-East Asia (Spradbery 1991).

The incidence and severity of the myiasis depend on local conditions: livestock distribution and density, wildlife populations and their migratory habits, human population density, and the effectiveness of public health services. However, most important are the climatic conditions. Screwworm populations vary during the year, being most abundant in the hot and humid season.

2. DIRECT AND INDIRECT BENEFITS OF NEW WORLD SCREWWORM ERADICATION

2.1. Benefits of Eradication in North America and North Africa

The main direct beneficiaries of the elimination of the New World screwworm are livestock producers. However, direct and indirect benefits result for the community as a whole, through the increased availability of locally produced livestock and dairy products, reduced deficiencies caused by a shortage of meat and milk, and the increased availability of draught animals and manure. At a national level, economic benefits arise due to better-integrated agriculture and livestock production, and reduced dependency on food imports. There may also be public health benefits to the community.

In North America, the economics of New World screwworm eradication programmes have been very positive, in spite of the high investment cost over the ca. 45 years of the programme (about USD 1300 million):

- USA: Cost to the United States Department of Agriculture (USDA) in 1958-1986 was about USD 650 million, in 2005 dollars (cost to producers and state governments not included) (Meyer 1994; J. H. Wyss, personal communication)
- México: USD 413.5 million (FAO 2005)
- Central America: USD 268.4 million (Wyss 2002)

Estimates of annual producer benefits show the very large economic benefits that are accruing (Wyss 2000, 2002a):

- USA: USD 896.1 million
- México: USD 328.6 million
- Central América: USD 87.8 million

The total annual producer benefits are USD 1300 million.

The Libyan campaign was estimated to cost close to USD 100 million from international funds, and it is a tribute to all concerned that successful eradication was achieved using less than USD 35 million, provided by a multidonor fund. This fund was established by the governments of Australia, Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Spain, Sweden, UK, and USA, and institutions such as the African Development Bank, European Economic Community, International Fund for Agricultural Development (IFAD), Islamic Development Bank, Organization of the Petroleum Exporting Countries (OPEC) Fund, and the World Wildlife Fund. An independent economic appraisal showed that the programme was a remarkably profitable investment, with benefit/cost ratios of 5:l in the infested zone, and 10:1 in the whole of Libya (Grindle 1991, FAO 1992, Vargas-Terán 2002b).

The New World screwworm was first described in 1857, infesting humans on Devil`s Island in French Guinea (Coquerel 1858). Screwworms still cause significant human morbidity and mortality in the tropical Americas, as well as dramatic effects on mammalian wildlife. It is estimated that, throughout the Americas, about 330 million people reside in New World screwworm-endemic areas. In most countries the human disease has been brought under control through strict medical surveillance and treatment, but where surveillance is relaxed, it threatens to develop into epidemic proportions. For example, before screwworm eradication in El Salvador, humans were found to be the third-most affected species (Reichard et al. 1992), and eradication relieved everyone of the personal risk of myiasis.

2.2. Importance of Livestock in South America

Livestock production in South America is based predominantly on medium- and small-sized farms raising small numbers of a variety of animal species. These animals are used for family consumption, draught power, and some for sale.

However, there is also an industrial commercial sector, which is totally market-oriented, and based primarily on cattie exports. Since the general economic situation is making remarkable improvements, this sector is growing very rapidly. Therefore South American animal agriculture is developing in a complex and dynamic environment. Livestock populations are shown in Table 1.

Table 1. Number (x 1000) of animals and humans at risk of infestation by the New World screwworm (Source: FAO, FAOSTAT (1999))

Country	Bovines	Equines	Suids	Ovines	Caprines	Total animals	Humans
Argentina	55004	3301	3200	14707	3428	79641	37032
Bolivia	6556	322	2714	8574	1500	19666	8329
Brazil	163470	6400	27425	18300	12600	228195	170115
Chile	3500	660	2750	4100	900	11910	15402
Colombia	25614	2450	2764	2195	1114	34137	42321
Ecuador	5105	521	2786	2180	284	10876	12646
French Guiana (France)	9	-	10	2	-	21	181
Guyana	220	2	20	130	79	451	861
Paraguay	9863	400	2500	395	131	13289	5496
Perú	4903	665	2788	13700	2068	24124	25665
Suriname	102	-	25	10	10	147	417
Uruguay	10700	500	360	15500	14	27074	3337
Venezuela	15992	500	4500	780	4000	25772	24170
Total	301038	15721	51842	80573	26128	475303	345972

2.3. Potential Economic Significance of Eradication in South America

Using data collected through surveys, and from economic studies carried out in the Caribbean region during the 1980s, Rawlins (1985) estimated the annual cost of New World screwworm surveillance and medication in various countries at USD 4.82-10.71 per head. If an average of USD 7.76 per animal per year is taken as the theoretical cost, then the annual costs of the New World screwworm in South America may be in the order of USD 3500 million (Table 2). Wyss (2002a) estimated the potential annual producer benefits for New World screwworm eradication in South America (in 2000) at USD 2800 million.

Table 2. Estimated annual losses from New World screwworm in South America

Country	USD (million)
Brazil	1770
Argentina	618
Colombia	264
Uruguay	210
Venezuela	199
Perú	187
Bolivia	152
Paraguay	103
Guyana	3
Suriname	1
Ecuador	0.17
French Guiana (France)	0.16
Chile	0

3. NEW WORLD SCREWWORM PROGRAMMES

3.1. Successful S1T Eradication Programmes in North America

The elimination of a residual indigenous screwworm population, after an intensive suppression programme, requires the area-wide application of the SIT. The SIT can most simply be described as a form of population control (Knipling 1985; Wyss 2002b; Klassen, this volume), supported by other disease-control activities including epidemiological surveillance, wound treatment, animal-movement control, and quarantine (Mangan, this volume). The eradication programmes, that over about 45 years implemented this integrated use of the SIT, have been phenomenally successful, as shown in Fig. 1 and Table 3 (Wyss 2000, 2002a; Klassen, this volume; Klassen and Curtis, this volume).

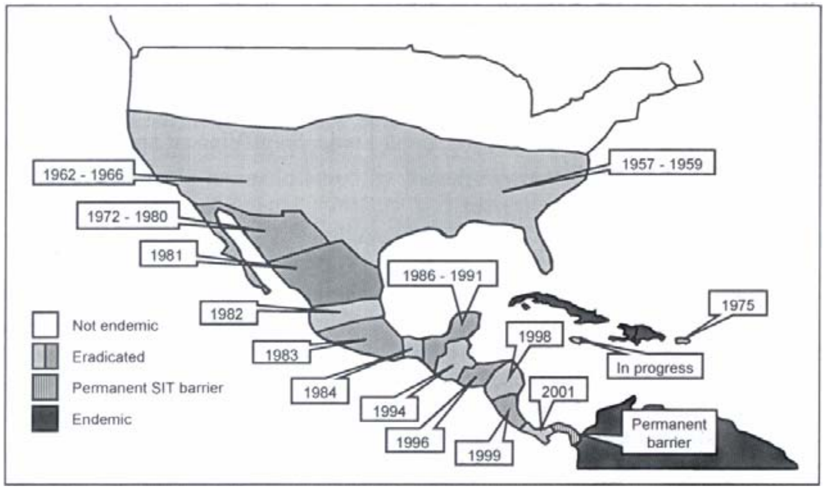

Figure 1. Progressive shift over time of eradication zones in the New World screwworm AW-IPM programmes using the SIT from the southern USA to the countries of Central America. (Map from Robinson 2002, reproduced with permission from Elsevier.)

Table 3. New World screwworm eradication programmes[1]

Country	Eradication period
USA south-east[2]	1957-1959
USA south-west[2]	1960-1966
México[2]	1972-1991
Guatemala[2]	1988-1994
Belize[2]	1988-1994
El Salvador[2]	1991-1995
Honduras[2]	1991-1995
Nicaragua[2]	1992-1999
Costa Rica[2]	1995-2000
Panamá[2]	1997-2000
Curacao[3]	1954
Curacao (reinfestation)[4]	1976
Puerto Ricos[5]	1975
US Virgin Islands[5]	1971-1972
British Virgin Islands[5]	1971-1972

[1]Information extracted from [2]Wyss 2000, [3]Knipling 1985, [4]Coppedge et al. 1980 and [5]Williamsetal. 1977.

3.2. Naturally Free Areas in North America

The countries and territories in the Caribbean, naturally free of the New World screwworm, are: Antigua and Barbuda, Bahamas, Barbados, Cayman Islands, Dominica, Grenada, Guadeloupe, Martinique, Montserrat, Netherlands Antilles (Aruba, Bonaire), Saint Kitts and Nevis, Saint Lucia, Saint Vincent and Grenadines, and Turks and Caicos Islands.

3.3. Remaining Endemic Areas in North America

Screwworm myiasis continues to be a serious animal and public health problem in Cuba, Dominican Republic, Jamaica, Haiti, and Trinidad and Tobago (Vargas-Terán 2002a; Klassen and Curtis, this volume). These countries pose a risk of New World screwworm reintroduction to those countries already free of the pest. Therefore the FAO and International Atomic Energy Agency (IAEA) have been providing technical assistance for New World screwworm suppression and eventual eradication

- Cuba (1995). The presence of the New World screwworm was officially acknowledged in 1995. The Cuban Government and FAO signed an agreement to establish a national suppression programme and design a project plan to implement screwworm eradication. The plan has two phases: (1) a pilot programme on Juventud Island, and (2) a full programme to cover the entire national territory. As a follow-up and part of the preparatory phase, the IAEA supported capacity building and an area-wide suppression trial on Juventud Island (García Rodríguez 2003, Méndez et al. 2005). The estimated cost of New World screwworm eradication is USD 62.5 million over 4 years. From 1995 to September 2003, 88 985 cases were reported. The animal species most affected were cattie, swine, sheep, goats, horses, dogs, and humans (FAO 1999, 2003).
- Dominican Republic (1999). Cases of the New World screwworm occur in all parts of the country, and without seasonal variation. Most neglected wounds and untreated navels of newborn animals soon become infested. Human cases are a common occurrence. In 1999, the governments of Jamaica, Haiti, and the Dominican Republic, and the FAO and IAEA, began regional technical assistance projects on capacity building and feasibility assessment of the suppression and possible eradication of the screwworm. As of February 2001, 1894 screwworm cases were diagnosed (FAO 2003).
- Haiti (1999). The disease is endemic, with a high incidence throughout the country. It causes considerable losses in domestic livestock, and affects people of all ages. A Government of Haiti and FAO technical project reported 684 myiasis cases, of which 669 were positive for the New World screwworm; seven of those cases were in humans. When the project terminated in 2001, it was expected that a joint eradication programme with the Dominican Republic would be established (FAO 2003).
- Jamaica (1998). Jamaica is one of the naturally screwworm-infested territories in the Caribbean. The high annual rainfall (over 1900 mm) and tropical climate sustain the very lush vegetation cover on the island, an ideal habitat for the New World screwworm. Consequently the fly is widely distributed, regardless of season, altitude or ecological conditions. The island has about 400 000 cattie, 440 000 goats, and a large but unknown number of "stray" dogs. There are no wild animals, e.g. deer, rabbits, opossum, and peccaries to support screwworm infestations. According to Snow et al. (1977), the New

World screwworm is the second-most important arthropod pest of livestock, exceeded only by ticks. The annual economic losses inflicted by the screwworm on the Jamaican livestock sector, in terms of animal mortality and increased production costs, in 1998 amounted to USD 5.5-7.8 million (Vo 2000). Although all ways of keeping livestock are affected by the screwworm, its eradication from Jamaica will have the greatest implication for the many subsistence farmers who depend largely on small animal holdings for their livelihood. The screwworm is also a severe human health problem, with 7 or 8 cases reported every month, and probably many more are unreported (M. J. B. Vreysen, personal communication).

In July 1998, the Government of Jamaica began a New World screwworm eradication programme, with assistance from the USDA and the cooperation of the IAEA and FAO (Robinson et al. 2000). The estimated cost was USD 9 million, and it was anticipated that 3 years would be required for completion (Vo2000). On average, from November 1998 to October 2004, 258 screwworm cases were reported each month. Weekly treatment of the island with sterile screwworm flies began in August 1999, with the release of about 16 million sterile flies per week. In mid-2002, in response to the prevailing high number of reported cases, a new strategy was adopted (M. J. B. Vreysen, personal communication). There have been several logistical problems associated with the programme, so in spite of the new strategy, and the continuing commitment of the Government of Jamaica to eradicate the screwworm, little progress had been made as of the end of2004 (Grant et al. 2000; FAO 2003; Box 1 in Dyck, Reyes Flores et al., this volume).

- Trinidad and Tobago. The New World screwworm is endemic, and cases are found throughout the year. Wounds left untreated usually become infested. The proximity of the islands to Venezuela, and possible immigration of flies, could complicate screwworm suppression and eradication.

3.4. Potential for Eradication in Remaining Endemic Areas of the Americas

3.4.1. Threat of Reinvasion

The Panama and US Governments have established a permanent biological barrier, in the Darien Gap in Panama, by releasing 50 million sterile New World screwworm flies per week, which contribute to the protection of the non-infested North and Central American countries. However, as long as Cuba, Dominican Republic, Haiti, and Trinidad and Tobago in the Caribbean, and several South American countries remain infested, they represent a high risk to the eradicated territories and the naturally screwworm-free countries in the Caribbean basin.

There are several examples of failure to prevent screwworm reinvasion in territories where it had been eradicated. In 1966, after eradication from the USA, a biological barrier was established along the Mexico-US border. However, in 1972, a massive failure of the barrier occurred (due to favourable weather conditions for the insect, and intensive legal/illegal livestock trade between the two countries); 90 000 cases were detected in the USA. Nevertheless, by 1984, eradication had been achieved in México down to the narrowest part of the country, and another barrier zone was established (Mexico-United States Commission 2002). Then, in 1985, several outbreaks occurred in the central and northern territories, in spite of the implementation and operation of good quarantine network.

The threat of reinvasion of the New World screwworm increases in proportion to the area eradicated, due to the risk posed by the international trade in animals, and the movement of pets and humans. Examples of screwworm outbreaks, both actual and potential, caused by such animal movements, are as follows: 1987 — dog from Honduras to the USA; 1988 — sheep from Latin America to Libya; 1989 — man from Panama to the USA; 1992 — woman from Brazil to New Zealand and Australia; 1994 — cattle from Central America to México; 1998 — woman from Trinidad and Tobago to UK; and 2001-2002 in Chiapas, México, due to the introduction of flies from Central America via a small aircraft. The cost of containment varies. In the case of Libya, the programme cost USD 75 million, and Mexico's largest outbreak cost USD 8 million.

3.4.2. Caribbean

The main objective of screwworm eradication in the Caribbean will be the promotion of sustainable agricultural development and food security, and simultaneously the protection of screwworm-free countries from reinvasion.

The Caribbean programme will demand the coordinated actions of all screwworm-infested and screwworm-free countries, as well as the institutions concerned with the suppression/eradication of the disease in the region. The experience and the resources accumulated by the Central and North American governments should be transferred to the infested countries in the Caribbean region.

The governments of the affected countries, with assistance from technical international agencies, will need to further refine national assessments of the current New World screwworm status, including geographical distribution, seasonal abundance, economic impact, and on economical methods to suppress the pest. Following these feasibility studies, a multi-disciplinary mission should prepare a project proposal for the eradication of the New World screwworm from the Caribbean, to be submitted to potential donors for funding, or a strategic alliance be established with countries already screwworm-free in the region.

In the first phase of the regional programme, Trinidad and Tobago should not be included, due to its proximity to the endemic countries of South America, and the associated real risk of reinvasion. However, once suppression/eradication activities are underway in the coastal areas of Venezuela, it should be given priority consideration.

Before launching such a regional programme, the following prerequisites should be resolved by the participant countries, donors, and stakeholders:

- The governments involved will be frilly committed to the New World screwworm eradication programme, and there will be no change in their policy
- Adequate funds will be available as required
- Adequate numbers of sterile insects of the desired quality will be available from the Mexican or Panamanian insect production facilities
- All infested areas in the Caribbean will be progressively treated
- All screwworm-free countries will maintain strong inspection and quarantine services to prevent the introduction of infested animals from endemic areas

3.4.3. South America

The New World screwworm is endemic throughout most of the South American continent (Vargas-Terán 2002a). All countries are infested except Chile, where the pest was last found in 1959 (although it is possible that Easter Island, a Chilean territory, remains infested). Although Chile shares borders with countries infested by the New World screwworm, it has been able to maintain its screwworm-free status as a result of strict controls imposed on the importation of animals and animal products. In South America, with the possible exception of

Chile, there are no natural barriers known to prevent the spread of screwworms between countries. The screwworm situation in the Amazon is not known, and the same can be said for the presence or absence of screwworms at different altitudes in the Andes.

Unless barriers can be found, for eradication purposes all of South America must be considered as one region. Once started, the programme would have to be progressive and continue until the whole continent (and thus the Southern Hemisphere) is completely free of the New World screwworm. To consider South America as a target area, considerable preparatory groundwork is needed. The governments and livestock producers in each country involved must be convinced that eradication is technically, practically and economically justified. They must be ready to commit the resources and the energy to complete the task. In addition to this groundwork, population genetic studies are being carried out (Lessinger et al. 2000) to understand more about screwworm population variation in the region, and the possible existence of isolated populations or cryptic species. There will also be a need for mating compatibility studies among the different populations in the region.

The following actions should be undertaken before the development and implementation of an eradication strategy:

- Conduct regional information campaign
- Develop baseline data on New World screwworm case incidence in each country
- Conduct studies on the economic impact of screwworms in each country
- Develop an eradication strategy
- Determine the cost of a regional screwworm eradication programme
- Determine the benefit/cost ratio
- Prepare an environmental-impact study on screwworm eradication in each country
- Identify methods of financing its implementation (Vargas-Terán and Wyss 2000)

3.5. Successful Eradication in Libya (1988-1992)

The discovery of the New World screwworm in North Africa in 1988 posed an immediate threat to Libya, the continent of Africa, and the Mediterranean region. It rapidly became clear that the price to be paid for the persistent and inevitable spread of this pest from its beachhead in the Libyan Arab Jamahiriya would be very great indeed — in terms of suffering and loss in domestic animal populations. Also the potential impact on wildlife in Africa was a grave concern to wildlife conservationists and enlightened people throughout the world (Van der Vloedt and Buttl990, Woodford 1992).

Based on a review of Libyan livestock importations, the source of the New World screwworm outbreak was thought to be sheep (infested with New World screwworms) imported from South America. This was the first report of the New World screwworm occurring outside the Americas, and this incursion confirmed the New World screwworm as one of the most important transboundary animal-disease threats.

Immediately after official confirmation of the New World screwworm in Libya, a series of governmental and United Nations activities began. The FAO established the Screwworm Emergency Centre for North Africa (SECNA), based in the Animal Production and Health Division in Rome, to coordinate surveillance and control activities; its field programme was set up in Tripoli, Libya (Vargas-Terán 2002b).

The FAO undertook the New World screwworm emergency programme in Libya on behalf of the countries threatened by the disease, and the 22 countries and agencies that provided the emergency funds (section 2.1.), including the technical support of the IAEA and other essential support provided by other United Nations agencies — IFAD and the United Nations Development Programme (UNDP).

To contain the outbreak, veterinary services in Libya provided 90 teams to undertake periodic inspections involving millions of animals in and around the infested area. Wounds were treated prophylactically, and the movement of livestock was control led. Prevention programmes in all neighbouring North African countries concentrated on surveillance, public information, and control of animal movements.

Containment activities were successful. The infested area around Tripoli had expanded only from approximately 18 000 to 25 000 km2 by the time field eradication activities commenced. As a consequence of the control of animal movement, no foci developed elsewhere in the region. However, the infestation had become more severe within the affected area, and more than 10000 cases were recorded in the second half of 1990, compared with less than 2000 in the same period of 1989(FA01991a,b).

From December 1990 to October 1992, 1300 million sterile New World screwworm pupae were transported from México to Tripoli, and the emerging flies were aerially dispersed over an area of 41 000 km^2 around Tripoli (Lindquist et al.,1993). The last New World screwworm case was reported in April 1991 (Krafsur and Lindquist 1996). After 14 months without evidence of the parasite, and under continuous surveillance and quarantine inspection activities, Libya was declared officially screwworm-free on 22 June 1992 (Vargas-Terán et al. 1994; Klassen and Curtis, this volume).

After eradication, the emphasis was on prevention. The FAO set a priority to improve the surveillance technology and quarantine infrastructure to reduce the risk of screwworms spreading from endemic areas. This animal disease prevention approach is the background to the creation of FAO special programmes, such as the Emergency Prevention System for Transboundary Animal and Plant Pests and Diseases (EMPRES), and the Regional Animal Disease Surveillance and Control Network for North Africa, the Middle East, and the Arab Peninsula (RADISCON).

4. POTENTIAL OLD WORLD SCREWWORM PROGRAMMES

The Old World screwworm is widely distributed, primarily in the Indian subcontinent and South-East Asia as far north as Taiwan and to Papua New Guinea in the south-east. It is present throughout mainland Papua New Guinea, except at altitudes of more than 2500 m above sea level, and high population densities of this screwworm have been found in the coastal swamplands adjacent to Torres Strait. The fly is present in New Ireland and New Britain, but not further into the Pacific. This screwworm species is also found in tropical and subtropical sub-Saharan Africa, and in several countries in the Middle East (Spradbery 2002). Kloft et al. (1981) reported repeated "transit infestations" of the Old World screwworm from South-East Asia to the Middle East, and a recent (1996) infestation recorded in Iraq is assumed to have originated from South-East Asia (Hall et al. 2001).

4.1. Feasibility of SIT Suppression or Eradication

At a conceptual level, any suppression and eradication programmes should first be initiated in the archipelagos of Indonesia and the Philippines, and other island nations such as Sri Lanka. Area-wide programmes could also be applied in peninsulas, such as peninsular Malaysia and southern Thailand, although a permanent buffer zone would be required at narrow interfaces between the eradicated and endemic zones, similar to the arrangement now in place for the New World screwworm in Panama. Treatment of islands should be extended progressively within a region before moving into the continental landmass.

On the Asian continent, the challenge would be much greater, similar to that of South America. Natural "ecological islands", bounded by deserts or high mountains unsuitable for screwworm survival, should be amenable to eradication programmes.

However, more ecological studies on the screwworm are required before such a strategy could be implemented. There may also be a potential, at the edge of the pests distribution, to reduce the range. This would be more feasible if the screwworm had already been eradicated in the "ecological islands" and peninsulas.

If an eradication attempt were to be made on the continental landmass, it would be essential that a regional approach be adopted.

Implementation of AW-IPM programmes using the SIT should target preferably the areas where the Old World screwworm is most vulnerable, and least able to migrate back to recolonize areas from which it had been eradicated.

4.2. Preparatory Activities

In most areas where the Old World screwworm is endemic, there is a paucity of information about its population size, distribution, and possible seasonal variation; in Malaysia, monitoring showed little variation (R. J. Mahon, unpublished data). However, there was considerable variation among farms, possibly due to differences in management and closeness of supervision, and thus efficacy in detection and treatment of myiasis. Anecdotal evidence suggests that the screwworm is a relatively minor problem under smallholder livestock production systems, but it becomes a serious production-limiting pest under more extensive grazing systems. Although farm records, where available, indicate that myiasis is a major animal-health problem under extensive grazing systems, screwworm suppression in large dairy herds is effective because the animals are observed closely every day, whereas herds of cattle and flocks of sheep require special mustering for inspection every few days, requiring a high labour cost that significantly reduces the efficiency of the production system.

Information about the incidence of Old World screwworm myiasis, and its significance for livestock production and public health, is limited. While this screwworm is reported widely, there are few reports of structured studies of the economic impact of the myiasis and of suppression measures; studies in Malaysia reported annual losses of USD 4.7 million (Feldmann and Slingenbergh 2002).

Before an eradication programme is planned, however, an essential preliminary phase is the collection of comprehensive baseline data, including ecological and genetic studies to delineate the relevance of the problem (Hall et al. 2001), the infestation dynamics, and the economic, public health and environmental costs of the pest (Dyck, Reyes Flores et al., this volume). Priority areas include:

- Distribution and seasonal occurrence
- Population density
- Incidence and severity of myiasis
- Economic impact studies
- Studies on screwworm migration behaviour
- Modelling of climatic and other effects on populations
- Application of geographic information systems (GIS)
- Genetic diversity
- Risk analysis

4.3. Other Important Considerations

Countries proposing to undertake an AW-IPM programme that integrates the SIT must have a strong commitment to it. This commitment must come not only from the government, to provide resources and an operational framework, but also there must be very strong support from, and involvement of, the livestock industry and relevant private-sector groups. AW-IPM programmes require considerable input from local people to support surveillance and monitoring programmes, and to suppress outbreaks of screwworms (Dyck, Reyes Flores et al., this volume).

Clearly, the programme must be economically viable, with a favourable benefit/cost assessment, and have adequate funds. Benefits accrue from increased livestock production (better performance of animals and fewer deaths), and reduced production costs and pesticide usage.

The AW-IPM programme may also provide considerable benefits that are hard to quantify economically, e.g. environmental benefits from reduced chemical usage and impact on wildlife, and possibly public health benefits. The large mammal fauna of northern Africa and Australia are at risk from incursions of screwworms.

Reductions in native fauna would impact tourism and ecosystems. In remote areas, or in areas with poor health services, there could be significant numbers of human cases. In the poorer regions of Central America, screwworm strikes in humans resulted in up to 40 mortality.

4.4. Australian Preparedness Planning for Potential Outbreaks

Australia is fortunate that neither the New World screwworm nor the Old World screwworm has become established in the country, although large Paris of its northern areas are environmentally suitable for these pests (Sutherst et al. 1989).

Introduction of the New World screwworm into Australia is considered unlikely, but not impossible. In 1992, an Australian tourist returning from South America accidentally brought, in a neck wound, live New World screwworm larvae into Australia (Searson et al. 1992). This occurred in May in southern Australia, when climatic conditions are unfavourable for the survival of the insect, but it demonstrates the potential for inadvertent introduction.

The Old World screwworm, prevalent in the neighbouring countries of Papua New Guinea and Indonesia, is a substantial threat to Australia. The export of live cattle from northern Australian ports to South-East Asian nations is an important and rapidly expanding trade. In 1988 in Darwin harbour, several Old World screwworm flies were found trapped in an empty livestock vessel that had just returned to Australia after delivering cattle to Brunei (Rajapaksa and Spradbery 1989). The Old World screwworm is also present near ports in the Middle East to which live sheep are exported from various Australian ports. Both of these situations provide an opportunity for the screwworm to enter Australia as larvae, pupae or adults in empty livestock-carrying vessels. While such vessels probably represent the most likely method for the pest to gain access to Australia, accidental transport on aircraft, active myiasis in humans or companion animals, are also possibilities.

In response to the threat of the Old World screwworm to the extensive pastoral cattle-producing areas in northern Australia, for many years Australia has conducted research on this pest. From 1973 to December 1991, the Commonwealth Scientific and Industrial Research Organization (CSIRO) studied the biology and ecology of the screwworm in Papua New Guinea. In 1982 and 1986, sterile flies were dispersed from the air to evaluate their effectiveness in eradicating the Old World screwworm. It was found that sterility could be induced in a wild population (Spradbery et al. 1989, Spradbery 1990), but the efficacy of the SIT against this screwworm species was not as high as that achieved by the USDA against the New World screwworm (Wyss 2000, 2002).

From 1995 to 2000, Australia and Malaysia undertook a collaborative myiasis control research project located at the Institut Haiwan, Kluang, Malaysia. The project assisted in suppression trials of the screwworm in Malaysia, and supported research that developed and evaluated improved Old World screwworm suppression and eradication techniques. To confirm and provide confidence in the efficacy of the SIT, a demonstration to show that mass-reared and sterilized screwworms were fit and competitive in the field was made (R. J. Mahon, unpublished data).

This species was reared successfully on a hydroponics diet. Most of the rearing methods for the Old World screwworm were based on the techniques developed by the USDA for the New World screwworm (Wyss 2002b), but innovations to mass-rear larvae were developed. A small pilot mass-rearing facility was built at the Institut Haiwan, where novel production-engineering methods were applied to rearing this species (Mahon and Ahmad 2000). In its present configuration, it has a potential output of about 6 million sterile flies per week. Unfortunately, the output of Old World screwworm larvae from a given volume of diet is significantly less than is obtained in the case of the New World screwworm. There is considerable scope to improve the efficiency of mass-rearing the Old World screwworm.

In 1990, to enhance the state of preparedness, Australia's long-term Old World screwworm preparedness was reviewed and a plan developed. Models of the impact of the Old World screwworm indicated that the cost of an invasion would be high. Anaman et al. (1993) estimated that the annual cost (at 1991 values) of an endemic establishment, to beef-cattle, sheep and dairy producers in an average climate year, would be approximately USD 200 million. In comparison with the cost to the community (several times the producer losses), these costs would be trivial (McKelvie et al. 1993). The models indicated that large areas of tropical and subtropical Australia are suitable for year-round survival of the Old World screwworm, with further southern extensions in summer that would recede in winter.

Extensive cattle-grazing is the dominant industry throughout much of the northern pastoral areas of Australia. Based on experiences in the USA, it is likely that extensive cattle production, as practised in northern Australia, would not be viable if the Old World screwworm became established. Failure of the livestock industries would, in turn, impact severely on the small- to medium-sized towns servicing the industries, and, as there are few or no viable alternative business opportunities, many communities could collapse. However, by undertaking an eradication programme, an 8:1 benefit/cost ratio would be achieved (Anaman et al. 1993).

Australia's native fauna is naive to this pest, and inevitably, should an incursion occur, there would be some impact on the fauna, although it is impossible to predict the extent of it. Human cases of screwworm myiasis might also occur.

Australia has developed contingency plans to respond to a number of exotic diseases, including the Old World screwworm, involving collaboration between the commonwealth and state governments and the livestock industries. The Australian Veterinary Emergency Plan (AUSVETPLAN 1996) contains a strategy for the suppression and eradication of the Old World screwworm should it gain a foothold on the continent (Tweddie 2002). The policy is to eradicate the screwworm in the shortest possible time, while limiting the economic impact using a combination of strategies including the following:

- Treatment of individual animals and groups to prevent or cure infestation, especially before movement
- SIT to suppress and eradicate the fly
- Quarantine and movement controls in declared areas to prevent the movement of infested animals
- Decontamination and disinfection of larvae-contaminated areas and things
- Tracing and surveillance to determine the source and extent of the infestation, and provide proof of freedom from the disease
- Zoning to define infected and disease-free areas
- Public awareness campaign to encourage rapid reporting of suspected infestations, and to facilitate cooperation from industry and communities

A fundamental plank in the eradication plan is integrating the SIT, which at present is probably the only feasible method that can eradicate an incursion of the Old World screwworm (or New World screwworm) into Australia. Being aware of earlier failures to scientifically establish its validity for this species, major elements of the preparedness strategy are to validate the SIT for the Old World screwworm in an endemically infested country, and to develop more efficient mass-rearing systems based on production-engineering principles.

It is envisaged that a facility producing 200-250 million sterile flies per week would be required. A facility with this capacity would be extremely expensive to construct, and there would be intense pressure to complete it as quickly as possible to prevent the screwworm from spreading and to minimize economic losses.

A design brief for a rearing facility (within Australia, if it were required), with a capacity to produce 250 million sterile screwworms per week, has been prepared (Phillimore 2002). Models have indicated that there is merit in constructing a facility, and then "mothballing it" until required.

A multi-species sterile insect production facility was another attractive option evaluated by Anaman et al. (1993). In the multi-insect-facility concept, the facility would be used to produce sterile insects for the suppression or eradication of endemic pests, e.g. Queensland fruit fly *Bactrocera tryoni* (Froggatt), Australian sheep blow fly *Lucilia cuprina* (Wiedemann), until an exotic pest incursion. After the exotic pest outbreak, the already-operational plant would fairly quickly be converted (in full or in part) to the production of sterile screwworms (or other exotic horticultural pests, e.g. the melon fly *Bactrocera* *cucurbitae* (Coquillett)). Since production would begin early in an outbreak, when the pest distribution was still restricted, a smaller capacity would be required.

The SIT could be ineffective if *Chrysomya bezziana* populations from different geographic locations proved to be a complex of sibling species (Strong and Mahon 1991; Krafsur, this volume). Studies were conducted to determine the genetic variation of *C. bezziana* samples from as many localities as possible within its geographic range (Hall et al. 2001), using a range of techniques including allozyme studies (Strong and Mahon 1991), some hybridization tests (J. P. Spradbery, unpublished data), cytogenetic studies (Bedo et al. 1994), and biochemical profiles of the exoskeleton chitin analysed by gas chromatography (Brown et al. 1998). While differences among populations occur, the studies indicated that it is not essential that the colony used to breed sterile flies for the SIT is derived from the same location as the targeted Old World screwworm population.

Other components of the strategy are designed to minimize losses and supplement the AW-IPM eradication programme. An early warning system, part of the North Australian Quarantine Strategy (NAQS), has been established. It is based on enhanced quarantine surveillance, education, and a regular trapping programme using "swormlure", an attractant for screwworm flies.

Ivermectin and avermectin are effective systemic pesticides against the larval stages of the Old World screwworm (Spradbery et al. 1991), and would be used to treat infected animals and those wounded in the course of normal husbandry procedures. Ivermectin boluses prevent screwworm myiasis for 102 days (Wardhaugh et al. 2001). Ivermectin boluses, or another long-acting formulation, could limit the incidence and spread of the Old World screwworm in extensive pastoral areas. This would reduce the population of screwworms, and perhaps thereby the incidence of myiasis, and certainly reduce dispersal. However native and wild animals would be a problem since they cannot be treated effectively.

Public awareness and early reporting of suspect myiasis are emphasized, both prior to, and in response to, an outbreak, especially in northern Australia. A video, entitled "Recognizing exotic livestock disease number 7: screwworm fly", has been produced to train veterinarians and other health professionals. To encourage the submission of larvae from myiasis strikes, specimen collection kits have been supplied to producers (and health centres) in northern Australia. Spradbery (2002) prepared a diagnostic manual, and people have been trained in identifying the Old World screwworm and differentiating it from other species.

5. CONCLUSIONS

The parasitic stage of the New World screwworm fly, documented for its transboundary importance, is an animal and human disease that causes significant sanitary and economic damage when it enters a country previously free of the screwworm. Screwworm-free countries must be informed about its epidemiology and methods of suppressing it, and establish appropriate prevention measures to avoid introducing it. Nowadays, with international transport, the globalization of economies, and the rapid long-distance movement of animals and animal products, the risk of transporting pests and diseases has greatly increased. As a result, stronger quarantine measures are being applied, with the potential of restricting free world trade. Some risks can be mitigated if the causal factor is removed. The elimination of the New World screwworm in North and Central America has removed an obstacle to animal movement within this zone.

Although in some areas the traditional methods of suppressing screwworms apparently give good results, the use of modern area-wide approaches must be considered to eliminate the disease. In addition, other positive benefits will arise. As a direct result of the screwworm eradication programme in North and Central America, national animal-health organizations in the region are now working closely together. Also, within each country, the government animal-health sector has built stronger bridges to producers. Since the screwworm programme directly involved producers, and depended on them to assist in the eradication, they also became part of the programme and took pride in the results; this stimulated cooperation in other programmes.

The modem area-wide approach to eradicate screwworms has proved to be successful. However, it is essential that the governments of affected countries in Africa, Asia, South America, the Caribbean, and the Middle East give political support to the elimination of the disease, and thus avoid continuous economic losses. As well, because of cutaneous myiasis in humans, screwworm eradication improves human health.

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