CHAPTER 7.2.

IMPACT OF FRUIT FLY CONTROL PROGRAMMES USING THE STERILE INSECT TECHNIQUE

W. R. ENKERLIN

*Joint FAO/IAEA Division of Nuclear Techniques in Food and Agriculture,
International Atomic Energy Agency, A-1400 Vienna, Austria
Email: W.R.Enkerlin@iaea.org*

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SUMMARY

Measuring the impact of area-wide integrated pest management (AW-IPM) programmes, that use the sterile insect technique (SIT) to control fruit fly pests of economic significance, is complex. These programmes affect practically the whole horticultural food chain. In this chapter, the impact of the programmes is assessed by focusing only on the benefits generated to producers and traders of horticultural products, the direct beneficiaries. This is done first by describing the types of benefits accrued from these programmes, second by explaining some of the main factors that influence programme benefits, and finally by presenting several examples to illustrate how the SIT technology, when properly applied for eradication, containment, suppression, or prevention purposes, can generate substantial direct and indirect benefits to the horticulture industry.

1. INTRODUCTION

Recently, the FAO (Food and Agriculture Organization of the United Nations) estimated that, to meet the projected food demand by 2050, global agricultural production will have to increase by 60% (FAO 2016). Area-wide integrated pest management (AW-IPM) programmes, that use the sterile insect technique (SIT) to control insect pests, including fruit flies of economic significance, can substantially contribute to meeting this demand by enabling the production of more and better-quality horticultural products at a lower cost, increasing supply, diversifying markets, creating new jobs, and all in a more sustainable environment-friendly manner. Measuring the impact of such programmes integrating the SIT is a complex task.

This chapter will concentrate more on the direct benefits generated by such programmes to beneficiaries — the producers and traders of horticultural products, although benefits impact the whole food chain system from farmers to consumers, passing through all the intermediate links of packing, shipping, distributing to wholesale and retail markets, and selling. In addition, the benefits branch out to other related businesses, such as suppliers of farm inputs, packing and raw materials, and some other services.

In the past decades, several studies have prospectively assessed the economic feasibility of potential fruit fly programmes integrating the SIT. These studies have been the basis for deciding to invest or not to invest in such programmes (Reyes et al. 1991; IAEA 1995; Enkerlin and Mumford 1997; Larcher-Carvalho et al. 2001; Vo et al. 2002; Larcher-Carvalho and Mumford 2004; IAEA 2005; Mumford, this volume). However, more relevant to this chapter are similar retrospective studies to measure the economic returns and impact of ongoing programmes at different stages

of implementation (USDA/APHIS 1993; Mumford et al. 2001; Kakazu 2002; Knight 2002; IICA 2009, 2010, 2013; Mumford, this volume).

This chapter assesses the impact of fruit fly programmes integrating the SIT. The most common direct and indirect benefits to the horticulture industry, especially to the producers and traders of horticultural commodities, are reviewed.

2. DIRECT AND INDIRECT BENEFITS

Inefficient pest control practices, or no control at all, result in direct and indirect losses from fruit flies that translate into direct and indirect benefits when using more effective alternative control methods and approaches such as the area-wide application of the SIT. For example, if direct fruit fly damage would normally cause a 25% loss in fruit yield, the area-wide application of an improved technology that reduces damage by 80% would lead to a direct benefit of a 20% increase in yield. Another example is the indirect damage from secondary pest outbreaks caused by killing natural enemies with regular insecticide “cover” sprays. If an effective and environment-friendly control technology is used, the amount of insecticide applied is reduced and more natural enemies survive to suppress the secondary pest populations; in this situation, a 10% indirect loss would potentially become a 10% indirect benefit.

The direct benefits commonly used to measure the impact of programmes integrating the SIT are:

- Increase in fruit yield and quality through reduced damage,
- Reduction in production costs through a more cost-effective control method.

The indirect benefits commonly used to measure the impact of programmes integrating the SIT are:

- Increase in fruit and vegetable export volumes, and market retention or diversification, through effective control of quarantine pests,
- Increase in export volumes through reduced rejections of commodities which do not comply with pest absence or the insecticide residue levels,
- Increase in fruit yield through reduced secondary pest outbreaks,
- Savings in medical costs, and occasionally deaths, through reduced exposure to insecticides, and also in legal costs arising from damage to private or public property as a result of insecticide misuse,
- Greater protection of beehives resulting in increased fruit yield through increased crop pollination,
- New jobs created in the horticulture industry and related businesses and services,
- Better human nutrition due to a per capita increase in fresh-fruit intake,
- Savings in environmental and public health costs through reduced insecticide residues in fruit, water reservoirs, and soil.

These indirect benefits are very difficult to assess and quantify, and in most cases have been accounted for only qualitatively (Pimentel et al. 1992).

The impact of programmes integrating the SIT has focused mostly on the direct benefits, but attempts have been made to quantify some indirect benefits using ad hoc methodologies (Enkerlin 1997). To partially quantify benefits to the

environment from using methods such as the SIT, the monetary value of savings accrued from minimizing insecticide use has been estimated (Pimentel et al. 1992). For example, in 1997, it was estimated that some Middle East countries (Israel, Jordan, and Territories under the Jurisdiction of the Palestinian Authority) would over 6 years, if current control practices prevailed, spend USD 46.7 million for insecticides to suppress the Mediterranean fruit fly *Ceratitidis capitata* (Wiedemann). This compares with only USD 5.8 million that would be spent on insecticides over the same period if pest suppression with the SIT were adopted, a direct benefit of USD 40.9 million in 6 years related to reduced insecticide use, in addition to the indirect environmental benefits (Enkerlin and Mumford 1997).

Another example of an indirect benefit is the per capita increase in fruit production. A study (Vo et al. 2002), to assess the economic feasibility of fruit fly control in the Central American region using the SIT, indicated that the average per capita production of fruits was 17.2 kg/year, substantially lower than the world's average annual per capita production of 75 kg in 2016 (FAO 2016). Effective fruit fly control in the Central American region would reduce current fruit damage and increase the annual per capita production of fruits in the short term by 10.5% to almost 19 kg/year, equivalent to 48 600 tonnes valued at USD 25 million/year. On a country basis, the amount of fruit (from fruit fly hosts) produced per capita per year is as follows: Costa Rica — 85 kg, El Salvador — 12.2 kg, Guatemala — 18 kg, Honduras — 11.5 kg, Nicaragua — 24.7 kg, and Panama — 16 kg. (There are no data available for Belize, but being a Mediterranean fruit fly-free country, with a traditionally friendly market under the Commonwealth umbrella, the per capita production can be assumed to be well above the regional average.) Clearly in Costa Rica, where the fruit industry is well organized and fruit production has been modernized, the annual per capita fruit production is comparable with the highest values in the world. On the other hand, in the other countries in the region, especially El Salvador, Honduras, and Panama, the annual per capita fruit production is extremely low — due to a lack of appropriate infrastructure, deficient growers' organizational schemes, and insufficient government incentives for fruit production and commercialization. Effective fruit fly control would permit the development of fruit fly low-prevalence and fly-free areas, paving the way for private investment in fruit production and commercialization for both the domestic and export markets, contributing to increases in per capita production, preventing chronic disease, creating new jobs, and stimulating the economy (Vo et al. 2002).

In Jordan, the cost of poisonings arising from using organophosphate insecticides against fruit flies was assessed. It was estimated that USD 1.6 million/year are spent for treatment of moderate to severe poisonings, and for labour-days lost. Each year an average of 94 tonnes of insecticide, i.e. technical material, are applied to control the Mediterranean fruit fly. This represents 33.8% of the total insecticide use in Jordan. Thus, assuming that sprays against this fruit fly cause a corresponding one-third of poisoning cases, about USD 550 000 are spent each year to treat persons poisoned when spraying against the Mediterranean fruit fly. In the assessment of total benefits that would be produced should the SIT technology be adopted to suppress this pest in Jordan, this cost was included in the indirect benefits (IAEA 2001).

Moreover, a study to measure the direct and indirect benefits of Mediterranean fruit fly control in the island of Madeira, Portugal (Dantas et al. 2004), was conducted using two valuation techniques. The first involves quantifying the costs incurred by society when dealing with the externalities caused by insecticides. In this case, only those costs that can be attributed specifically to the use of insecticides for Mediterranean fruit fly control in fruit crops are included. The second method, used for environmental valuation, is called “contingent valuation”. This method is based on the choices people make when they are presented with a variety of goods and services; a “willingness to pay” (WTP) indicates a positive preference. Quantification of the indirect benefits accrued from using the SIT for Mediterranean fruit fly suppression in Madeira makes economic returns positive in two out of three control scenarios analysed (IAEA 2005).

The benefits generated by programmes that control fruit flies with an “integrated SIT approach” will be determined and shaped mainly by the characteristics of the pest problem, including pest status (presence or absence), level of pest risk, and access to the targeted market, as well as by programme strategic options (section 3.2.; Hendrichs, Vreysen et al., this volume). There are other factors that will influence the benefits: the type of organization (public, private or joint ventures) and organizational structure (centralized, decentralized or a combination) used to execute the programme, the level of participation of the main stakeholders, the readiness to take advantage of the improved phytosanitary condition, increased fruit production and quality including the necessary means for commercialization in national and international markets, global market supply-demand forces, and the strategic approach and tactics selected to achieve programme objectives (of particular relevance are the size of the intervention areas and the time period required to achieve the pest control goal).

A brief explanation of how some of these factors, in particular organizational structure, stakeholder participation, and programme strategic options, affect the benefits produced by programmes applying the SIT, and hence their impact, is presented in the following section.

3. FACTORS THAT AFFECT BENEFITS PRODUCED BY PROGRAMMES USING THE SIT

3.1. Organizational Structure and Stakeholder Participation

To date, most fruit fly programmes integrating the SIT have been public projects, operated through a centralized federal government structure, with different degrees of participation from local governments, and with limited participation from the horticulture industry at the farm level. Often these have been prevention and emergency response programmes aimed at protecting the welfare of the horticulture industry, keeping out quarantine pests or eliminating outbreaks of recently introduced invasive pests. A typical example of such programmes is Chile’s National Fruit Fly Programme aimed at maintaining fruit fly-free status through an effective early detection and emergency response system, operated by the

Agriculture and Livestock Service of the federal government (Olalquiaga and Lobos 1993; section 4.2.).

Other types of programmes include those where strong alliances have been formed among the federal and local governments and the fruit industry, which share capital investment, operational costs, and responsibilities. These programmes aim to control established key fruit fly pests that, by directly affecting production and commercialization, limit the development of the horticulture industry. A typical example of such programmes is the National Fruit Fly Campaign of the Mexican government (SAGAR/IICA 2001; section 4.6.).

As the SIT technology becomes more cost-effective when compared with other more-conventional methods of fruit fly control, interest from the private sector in its application has slowly increased. Public-private organizational schemes, in which governments, the horticulture industry, and other private and/or civil organizations form alliances and partnerships for financing and operating area-wide programmes integrating the SIT, are becoming more common. In some cases, the participation of federal and local governments will be limited to a supporting role, e.g. creating the legal framework for smooth implementation of programme activities, and setting standard operating procedures (SOPs) in the form of phytosanitary norms for the production, shipment, importation, and release of sterile flies. Also, when required, governments must enforce quarantine regulations. An example of a scheme where the private sector has become involved in area-wide fruit fly control is the fruit fly suppression programme in the Hex River Valleys and other fruit producing areas in the Western Cape Province of South Africa, in operation since 1997 (Barnes et al. 2004; section 4.4.), and covering more than 22 000 ha of commercial deciduous fruit and table grapes (Venter et al. 2021).

As predicted earlier, and given prevailing diverse political and economic environments, programmes integrating the SIT will operate under different types of organizational structure. Countries such as Argentina, Australia, Brazil, and Morocco are operating programmes run by government-private sector alliances, and even some programmes or segments of programmes are operated fully by the private sector, for example in Israel and South Africa, but other countries, e.g. Belize, Chile, Croatia, Dominican Republic, Peru, Guatemala, Mexico (Moscamed), Spain, and the USA conduct mostly government-managed programmes. A key element for success in government or semi-government programmes is that the financial resources must be available in sufficient amount and with no delays according to an agreed technical and financial operational plan. Resources should be administered under an unbureaucratic flexible scheme where the budget adapts to the requirements and dynamics of the programme's operations, and not the programme to the budget (Enkerlin et al. 2017; Dyck, Reyes Flores et al., this volume).

Government-run programmes come at a low cost to the direct beneficiaries, since most of the required capital and operational inputs are fully or partially subsidized, and normally governments do not seek cost-recovery. If the programme is effectively executed, the beneficiaries start to accrue benefits or profits quickly. However, these programmes rely on political and economic stability, and under certain conditions the managerial and technical capabilities of governments are more exposed to failure. Since programmes integrating the SIT are financially demanding

and management intensive, countries that decide to embark on such programmes must have a strong long-term political commitment and fulfil a minimum institutional capacity to manage them. Countries that begin a large-scale SIT governmental project, with little or no support and participation of the private sector, and no support from international organizations and other relevant stakeholders, are likely to fail in the endeavour. This situation contrasts with programmes that are established as strategic alliances between government and private sector, with the support of international organizations, and where the stakeholders are actively involved in programme execution or supervision. Under this scheme, with private assets and financial capital invested in the programme, there is little or no government subsidy. Direct beneficiaries and other stakeholders have to wait longer for payback of the initial investment, and for profits to start flowing. However, in the long term, since they are not so dependent on political stability and programme management is normally carried out more effectively, these programmes tend to be more sustainable.

3.2. Programme Strategic Options

Based on the goals of the programme, and the status of the target pest in the area of interest, fruit fly programmes integrating the SIT can be grouped into four main strategic options, as follows: (1) eradication — eliminate from an area an established pest or an outbreak of an introduced pest to establish pest free areas, (2) suppression — reduce pest populations to establish low pest prevalence areas, (3) containment — apply phytosanitary and regulatory measures in and around an infested area to prevent the spread of the pest, and (4) prevention — apply phytosanitary and regulatory measures to prevent the introduction or reintroduction of a pest into a pest free area (FAO 2017; Hendrichs, Vreysen et al., this volume). Suppression, eradication, containment, and prevention programmes can provide the same types of direct and indirect benefits listed above (section 2.). However, in terms of required inputs, economic returns and subsequent impact, there are marked differences among these four types of programme.

In areas with a high risk of introductions, the most profitable strategy of using the SIT is prevention. It is always much more cost-effective to protect proactively a pest free area from the introduction and establishment of a pest than having to “live with” or eradicate it. However, when the target pest has already become established in an area, the options for using the SIT to control the pest are eradication, suppression, or containment.

Figure 1 shows a typical net-benefits trend for three control options — SIT suppression, SIT eradication, and insecticide-bait suppression. Net-benefits tend to be greater in an eradication programme than in a suppression programme. After eradication has been achieved, and the area has been certified fly-free, horticultural products can be exported to fly-free high-value markets without complying with expensive postharvest treatments and other quarantine regulations. Furthermore, the ongoing cost of maintaining an area fly-free (detection networks, quarantine regulations, and in some cases the release of sterile flies), although costly, would normally be lower than the cost of a permanent SIT suppression programme.

Figure 1. Typical net-benefit trend for three control options: SIT eradication, SIT suppression, and insecticide-bait suppression. (Figure adapted from Enkerlin and Mumford 1997.)

Once the eradication goal has been reached and benefits fully established, the combination of higher gross revenues at a lower cost makes the eradication approach more economical than the suppression approach (Fig. 1). However, an eradication strategy requires greater initial capital investment than a suppression strategy. In addition, after eradication has been achieved, the fly-free area will be exposed, depending on the situation, to a certain risk of reinfestation (quarantine operations are vulnerable and subject to some degree of failure). Recurrent pest outbreaks require costly emergency programmes to eradicate the reinfestations, and the enforcement of quarantine restrictions by trading partners can last for months or even years. This cost needs to be included when calculating the total cost of an eradication programme. There are situations where the risk of reinfestation is very high, and an eradication programme is not economically justifiable if there are recurrent outbreaks that disrupt agricultural trade; the stakeholders would be better off with suppression, which entails a lower risk. Alternatively, a preventive release programme can be cost-effective in situations where there is a high risk of reinfestation (Hendrichs, Vreysen et al., this volume; Mumford, this volume).

From technical and economic points of view, any one of the strategic approaches described above may, in a particular situation, be the best option. However, in some situations, the establishment and strict enforcement of quarantine barriers would be too disruptive to trade, excluding the eradication option. The choice depends on the conditions prevailing in the target area, such as the pest's status, the geography and ecology of the area, the available resources and overall plant protection and quarantine infrastructure, and the commitment and level of participation of stakeholders and their willingness to take risks. Therefore, it is critical that a decision to embark on one or the other approach is based on technically and economically sound analyses of the pest problem.

4. BENEFITS ACCRUED FROM FRUIT FLY PROGRAMMES USING THE SIT

The SIT can be a cost-effective component of the AW-IPM of some of the most important fruit flies of economic significance, such as the Mediterranean fruit fly, oriental fruit fly *Bactrocera dorsalis* (Hendel), melon fly *Zeugodacus cucurbitae* (Coquillett), Mexican fruit fly *Anastrepha ludens* (Loew), West Indian fruit fly *Anastrepha obliqua* (Macquart), Queensland fruit fly *Bactrocera tryoni* (Froggatt), and Caribbean fruit fly *Anastrepha suspensa* (Loew) (Nigg et al. 2004).

In the past, at least 27 AW-IPM programmes in the world have integrated the SIT to control fruit flies. In Table 1, they are grouped by the strategic options pursued, i.e. eradication, suppression, containment, prevention, and combinations thereof (section 3.2.; Hendrichs, Vreysen et al., this volume). A few programmes have been selected to illustrate the benefits that have been produced.

Most of the data available on programme benefits and impact are based on quantifications of direct benefits, and in a few cases indirect benefits are also included. However, most of the indirect benefits are usually not accounted for, and therefore in most cases the overall benefits of these programmes are underestimated. Nevertheless, it is very evident that, when the technology is applied properly, the programmes generate substantial benefits to the horticulture industry and to society.

4.1. Fruit Fly Prevention Programme — California, USA (Box 1)

4.1.1. Problem Definition

The Mediterranean fruit fly is a serious threat to California's economy. For the fruit industry alone, the annual value of susceptible crops in 2002 was about USD 4700 million (CASS 2002; USDA/NASS 2002, 2003a, b). The rate of introduction of this non-native pest, which can attack more than 250 different crops (Liquido et al. 2014), has been increasing with growing trade and tourism. Since 1975, more than USD 256 million (in state and federal funds) have been spent to eradicate small and large infestations, primarily in urban areas of the Los Angeles Basin and the San Francisco Bay area.

Table 1. Fruit fly AW-IPM programmes that integrated the SIT, grouped by strategic option

Strategic option	Programme
Prevention	<p>Mediterranean Fruit Fly Preventive Release Programme (Los Angeles Basin, California, USA), 1996 – present</p> <p>Mediterranean Fruit Fly Preventive Release Programme (Tampa-Palm Beach-Miami, Florida, USA), 1998 – present</p> <p>Mexican Fruit Fly Preventive Release Programme (Rio Grande Valley, Texas, Mexico – US border), 1980s – present</p> <p>Mexican Fruit Fly Preventive Release Programme (Tijuana, Baja California, Mexico – US border), 1980s – present</p> <p>National Fruit Fly Control Programme (Chile), 1996 – present</p>
Containment	<p>Mediterranean Fruit Fly Programme “Programa Moscamed” (Guatemala, Mexico, USA), 1983 – present</p> <p>Binational Chile-Peru Programme for Mediterranean Fruit Fly Eradication, 1996 – present</p> <p>Queensland Fruit Fly SIT Control Programme (South-Eastern Australia), 1980s – present</p>
Eradication	<p>Mediterranean Fruit Fly Programme “Programa Moscamed” (Guatemala, Mexico, USA), 1978 – 1982</p> <p>Melon Fly Eradication Programme (Okinawa, Japan), 1978 – 1993</p> <p>Oriental Fruit Fly Eradication Programme (Guam), 1963 – 1964</p> <p>National Mediterranean Fruit Fly Programme (Chile), 1990 – 1995</p> <p>Carnarvon Medfly Eradication Project (Carnarvon, Australia), 2016 – present</p> <p>Mediterranean Fruit Fly SIT Control Programme (Southern Australia), 1980s – present</p> <p>Mexican Fruit Fly and West Indian Fruit Fly Eradication Programme (Northern Mexico), 1988 – present</p> <p>Mediterranean Fruit Fly Eradication Programme “PROCEM” (Mendoza – Patagonia, Argentina), 1992 – present</p> <p>Mediterranean Fruit Fly Eradication Programme (Altagracia, Dominican Republic), 2015 – 2017</p>
Suppression	<p>Mediterranean Fruit Fly Suppression Programme (Arava, Israel), 1994 – present</p> <p>Mediterranean Fruit Fly Suppression Programme (South Africa), 1997 – present</p> <p>Oriental Fruit Fly Suppression in Pilot Areas (Thailand), 2000 – present</p> <p>Melon Fly, Oriental Fruit Fly, and Mediterranean Fruit Fly Area-Wide Integrated Pest Management Program (Hawaii), 1960s – present</p> <p>Mediterranean Fruit Fly Suppression Programme “Programa Madeira-Med” (Portugal), 1998 – 2008</p> <p><i>Bactrocera</i> spp. Pilot Suppression Programme (Guimaras Island, Philippines), 1996 – 1999</p> <p>Mediterranean Fruit Fly Suppression Programme (Israel/Jordan), 1994 – present</p> <p>Mediterranean Fruit Fly SIT Control Programme (Peru), 1970s – present</p> <p>National Fruit Fly Campaign (Central and Southern Mexico), 1991 – present</p> <p>Mediterranean Fruit Fly Suppression (Tunisia), 2001 – 2007</p> <p>Mediterranean Fruit Fly Suppression Programme (Valencia, Spain), 2005 – present</p> <p>Mediterranean Fruit Fly Suppression Programme (Neretva Valley, Croatia), 2009 -- present</p> <p>Mediterranean Fruit Fly Suppression Programme (Agadir, Morocco), 2010 -- present</p>

4.1.2. *Major Achievements*

The Preventive Release Program (PRP) has resulted in a 96% reduction in the number of wild Mediterranean fruit flies caught in the treated Los Angeles basin, and more than a 96% reduction in the number of fly infestations. Before the change in 1994 to an area-wide approach (1987–1993), an average of seven or eight Mediterranean fruit fly outbreaks occurred every year, costing the state approximately USD 33 million per year (USDA/APHIS 1992). Since the implementation of the PRP in 1996, and after eliminating all outbreaks, the overall cost of the programme has been cut in half, and only a few small Mediterranean fruit fly infestations have occurred within the boundaries of the release area. These infestations remained confined and were quickly eliminated without applying aerial sprays of toxic bait and without trading partners establishing temporary quarantines for Californian exports.

Box 1. Mediterranean Fruit Fly Preventive Release Programme (PRP) in the Los Angeles Basin, California Department of Food and Agriculture (CDFA 2002)

After years of using the conventional reactive approach, i.e. detecting and eradicating Mediterranean fruit fly infestations at a local level, in 1994 the control strategy shifted to a proactive approach that emphasized area-wide measures over the whole Los Angeles Basin, including twice-weekly sterile-male releases. In view of its success, this release programme has continued preventively since 1996, and has become a major component of CDFA's comprehensive approach to prevent this pest from becoming established in California (Dowell et al. 2000). This programme is jointly coordinated and operated by county, state, and federal authorities.

4.1.3. *Estimated Benefits*

The impact of this programme has been measured in terms of the potential economic losses that the pest would inflict on the horticulture industry and home-garden fruit production if it became established in California. The parameters that have been used to measure the impact are the following: yield loss in agriculture and home-garden production, increased insecticide use (from 127 to 2270 tonnes/year of active ingredient), loss of export markets, and annual quarantine compliance costs (CDFA 2002). In 1991 it was estimated that a permanent Mediterranean fruit fly infestation could cost California's economy USD 1300–1900 million annually (yield loss, control costs, quarantine compliance costs, and loss of export markets, not including the social and environmental costs), with the loss of 14 000 or more jobs (Siebert and Pradham 1991). The current estimated benefit/cost ratio (BCR) of the PRP programme in California ranges from 87 to 187 (K. Hoffman, personal communication).

The insecticide savings (amount of active ingredient not used) have been very large. If the CDFA had continued to apply aerial toxic-bait sprays on the same 3800-km² area that was infested in 1994, some 458 tonnes of malathion would have been used (CDFA 2002). In contrast, since implementing the basin-wide sterile Mediterranean fruit fly releases, only a small amount of insecticide has occasionally been applied against pest incursions as part of the emergency reaction plan to some of the reduced number of Mediterranean fruit fly outbreaks that still occur periodically in California.

4.2. Fruit Fly Prevention/Containment Programme — Chile (Box 2)

4.2.1. Problem Definition

An important component of the Chilean economy is the production and export of fruits and vegetables, worth about USD 2000 million annually. As a prerequisite to importing these commodities, some of the main commercial partners, e.g. USA and Japan, require that produce be grown in certified fruit fly-free areas. Except for Arica province at the northern tip of the country, and occasional outbreaks in other provinces, Chile has historically been regarded as a fruit fly-free country. However, some countries used the presence of the Mediterranean fruit fly in northern Chile as a pretext to close their markets to Chilean horticultural products; as a result, since the 1980s, this stimulated significant eradication efforts in Arica province. Following various failed attempts to eradicate the Mediterranean fruit fly from northern Chile using baits sprays, in late 1990 the SIT was introduced. After 6 years of an intensive integrated area-wide programme, in 1995 the fly was eradicated in Arica, and Chile was declared a fruit fly-free country (MAG/SAG 1995).

4.2.2. Major Achievements

Since its inception in 1980, Chile's National Fruit Fly Programme has, through effective surveillance and eradication activities, successfully kept the country free of economic species of fruit flies. Chile's programme to remain fruit fly-free is one of the best in the world.

Strengthening binational cooperation with Argentina and Peru, and formalizing binational cooperation with Bolivia, are the cornerstones that sustain Chile's fruit fly-free status.

4.2.3. Estimated Benefits

Since Chile was declared a fruit fly-free country, fruit exports have grown to an annual 320 million boxes of fruits, mainly table grapes, apples, stone fruits, kiwis, and avocados, valued in 2016 at USD 4000 million (ASOEX 2017).

Each year the government of Chile spends on average USD 4 million to keep the country free of fruit flies. If multiple outbreaks occurred in Chile's Metropolitan Region, the industry would lose an estimated USD 78 million per year, just in market loss and compliance with US quarantine regulations. Chilean exports of fruits and vegetables are valued at approximately USD 4000 million per annum. If this figure is divided by the average annual cost of the national programme, a BCR of 1000:1 is obtained. This ratio would be even higher if other cost factors, e.g. control costs, yield losses, and general social and environmental costs, were included (Lindquist and Enkerlin 2000; R. Rodriguez, personal communication).

Chile's National Fruit Fly Programme (Box 2) has been the driving force behind the expansion of the fruit and vegetable export industry, one of the main contributors to the country's gross domestic product (GDP).

Box 2. National Fruit Fly Programme in Chile

Chile's fruit fly-free status has allowed one of the most important export-oriented horticulture industries in the world to develop. To protect this valuable asset, in 1980 the Government of Chile, through the Servicio Agrícola Ganadero de Chile (SAG) of the Ministry of Agriculture (MAG), created Chile's National Fruit Fly Programme — to prevent the introduction and establishment of any fruit fly species of economic importance, including the Mediterranean fruit fly and the economic species in the genera *Anastrepha* and *Bactrocera* (Olalquiaga and Lobos 1993).

The National Fruit Fly Programme in Chile operates through a centralized organizational structure of the Ministry of Agriculture. As part of a regional approach to the fruit fly problem, the Government of Chile has subscribed binational agreements with Argentina and Peru. Through these agreements the quarantine infrastructure and fruit fly control activities in these neighbouring countries have been strengthened, and thus the risk of introducing fruit fly pests from these countries has been reduced.

Chile has achieved its fly-free status by implementing two major strategic activities:

1. Effective national and international quarantine system (including interprovincial quarantine road stations and international quarantine at ports of entry), and an extensive and highly sensitive fruit fly-trapping network to detect fruit fly introductions at an early stage. Outbreaks of exotic fruit flies, mainly the Mediterranean fruit fly, have been eradicated through the effective execution of an emergency eradication plan based on detecting and eradicating infestations. A *B. dorsalis* outbreak on Easter Island was eradicated in 2011 at a cost of USD 100 000 (AGROMEAT 2017).
2. In Arica province, the ongoing Mediterranean fruit fly AW-IPM programme that integrates the SIT functions as a containment barrier to avoid the natural or artificial spread of fly populations into northern Chile, protecting the main fruit and vegetable production areas in the central and southern parts of the country.

For years, Chile has been subjected to increasing risks of pest introductions through more trade, tourism, and people coming from neighbouring countries. Consequently, there has been an increase in the rate of Mediterranean fruit fly detections and outbreaks. Nevertheless, the Government of Chile (through SAG) has strengthened its National Fruit Fly Programme by gradually incorporating state-of-the-art technology. This includes introducing an improved genetic sexing strain of the Mediterranean fruit fly into the mass-rearing facility in the Lluta Valley (Arica province), DNA-identification techniques to assess the geographical origin of introduced flies, updated fly-trapping systems, and X-ray machines at critical points of entry to facilitate detection and confiscation of fruit that are hosts of the Mediterranean fruit fly (Lindquist and Enkerlin 2000; Gonzalez and Troncoso 2007).

*4.3. Fruit Fly Eradication Programme — Japan (Box 3)**4.3.1. Problem Definition*

In its current distribution range, the melon fly is the most destructive pest of cucurbit crops. It is found in Africa, India, South-East Asia, and islands in the Pacific (including Hawaii). In Japan, it was first discovered in 1919 in the Yaeyama Islands, and between 1919 and 1970 it invaded most island groups in the south of Japan. In Okinawa, this pest affected more than 40 important vegetables and fruits, inflicted substantial direct damage to fruits, and prevented the export of these infested commodities to fly-free areas.

Sugarcane was the most important cash crop in Okinawa, accounting for about 50% of cultivated land and 20% of all farm income. However, as a result of stagnant prices and productivity, as well as increased international competition, income from sugarcane production declined significantly. Okinawa's sugar industry survived only because of the government's price-support programme. As a result, farmers and the local government needed to diversify from monoculture sugarcane-centred agriculture into other cash crops, e.g. flowers, and tropical vegetables and fruits such

as mango. The other promising agricultural strategy was to produce “healthy” food, and for Okinawa to become a brand name for “healthy longevity” because of its world-renowned “healthy island” image.

Due to this situation in Okinawa, in the early 1970s the eradication of the melon fly became the top priority project at local and national levels. The problem was urgent since the fly was rapidly spreading to other islands and, unless specific eradication measures were undertaken, might spread to mainland Japan.

4.3.2. *Major Achievements*

- First successful use of the SIT for melon fly eradication in island communities,
- Eradication was achieved with no harm to the health of the public or the environment,
- Lifting of internal quarantine regulations to allow transport to non-infested areas resulted in significant expansion of major horticultural products,
- Training of foreign technicians in the AW-IPM of the melon fly.

Box 3. Melon Fly Eradication Programme in Okinawa, Japan (Kakazu 2002)

Okinawa's prefectural government, with the support of the Japanese national government and active participation of staff of municipalities (mainly in field operations) and agricultural cooperatives, operated the programme. In 1972, an experimental melon fly eradication project using the male annihilation technique (MAT) and the SIT was conducted in Kume Island. Following successful eradication, in 1978 a project was initiated that gradually covered most archipelagos in the south of Japan; it was completed in 1993. In view of the geographic closeness of the southernmost islands to Taiwan, where the melon fly is present, in these islands the programme currently conducts a continuous detection, quarantine, and preventive release operation against re-establishment of the pest.

4.3.3. *Estimated Benefits*

A post-programme economic assessment, prepared by the Research Institute for Subtropics (Kakazu 2002) using the methodology described by Enkerlin and Mumford (1997), clearly shows the benefits of melon fly eradication. The estimated net-benefits are those arising from the commercial shipments of commodities that are hosts of the melon fly. Not included in the assessment were indirect benefits for the island economies, such as human health and environmental protection, insecticide-free farming, preservation of natural enemies, savings in fumigation and quarantine costs, and above all preventing the insect from spreading to the mainland of Japan. Furthermore, due to data constraints, the indirect social benefits were not estimated. The programme proved to be economically viable, even though only the increase in commodity shipments was considered in the benefit equation.

If the northward spread of the melon fly had not been stopped, the potential loss for farmers and the horticulture industry in general would have been very substantial, and the cost of an eradication programme would have risen enormously. As a result of the successful eradication programme, the production of Okinawa's high-valued niche products, such as bitter melon and mango, have risen sharply. Between 1990 and 2000, bitter melon production rose from 2720 to 6220 tonnes, a 2.3-fold increase. Similarly, over the same period, mango production increased from 278 to 1290 tonnes, a 4.6-fold increase; all together this is equivalent to USD 335

million in 10 years. (These benefits are underestimated since the savings from fumigation and quarantine costs were not included in quantifying the benefits.) This figure should be compared with the much lower total programme cost, USD 172 million, during the 16-year eradication period (1978–1993).

In 1996, 3 years after achieving eradication in the last islands (Yaeyama Islands), the programme reached its break-even point and repaid the initial investment. Between 1997 and 2000, the programme cost was estimated to be USD 31 million, but gross revenues were USD 167 million (from the sale of commodities shipped to mainland Japan and other countries). If the total accumulated gross revenues are divided by the total accumulated costs during this time period, the BCR shows that 5.4 dollars were returned for each dollar invested. For a public investment project in Japan, it is a remarkable achievement that the programme was generating positive net-benefits only 3 years after eradication.

4.4. *Fruit Fly Suppression Programme — South Africa (Box 4)*

4.4.1. *Problem Definition*

The Mediterranean fruit fly and the Natal fruit fly *Ceratitis rosa* Karsch occur in the Western Cape province, South Africa. The Hex River Valley is a major production area for table grapes; an average of 15.5 million cartons is exported annually. The dominant and economically important species is the Mediterranean fruit fly. It causes direct damage to fruit, requiring costly insecticide sprays, and infested fruit results in rejections of boxed table grapes by the phytosanitary inspectors of importing countries (Barnes and Eyles 2000; Barnes et al. 2015; Barnes 2016).

4.4.2. *Major Achievements*

Growers and scientists now understand the benefits of applying the concept of AW-IPM and the advantages to international trade of establishing low pest prevalence areas (FAO 2017). They also have effectively adopted the SIT technology and established the required infrastructure, which is now managed by the private sector. According to growers in the valley, integrating the SIT to suppress the Mediterranean fruit fly has been very successful. In the 3 years (1997–1999) before the release of sterile flies, fly mean population levels were 0.9–1 flies per trap per day, but in 3 years of the release period (2000–2002) the levels decreased to 0.1–0.4 flies per trap per day. From 1997 to 2002 insecticide use dramatically decreased (Barnes et al. 2004). These positive results have encouraged other associations of fruit growers outside the Hex River Valley to embark on SIT activities as well.

4.4.3. *Estimated Benefits*

By using environment-friendly technology, and reducing production costs and increasing revenues, the Mediterranean fruit fly suppression programme increased the profits of the table-grape industry in the Hex River Valley. By replacing insecticide applications with a combination of aerial and ground releases of sterile male flies at hot spots, the reduction in control costs was substantial, from USD

350 000/year with chemical control to USD 130 000/year with the SIT. Rejections, due to fruit fly infestation, of exported cartons of table grapes from the valley were reduced by approximately 50%. In 2000, a reduction of 60% in rejection of cartons by phytosanitary inspectors of importing countries represented savings of USD 150 000. For the 2001/2002 season, the direct benefits totalled USD 370 000/year, at a cost of USD 130 000, which is equivalent to a BCR of 2.8:1.

The expected medium-term impacts of the area-wide project include:

- Expanding export markets by meeting sanitary and phytosanitary restrictions,
- Creating new jobs in agriculture (not only for large producers, but also emerging small producers) and related industries,
- Strengthening regulatory, research and development support of the fruit industry,
- Protecting the environment and the health of farm workers.

Box 4. South Africa Mediterranean Fruit Fly Suppression Programme (IAEA 2002)

In 1997, a pilot project to control fruit flies integrating the SIT was implemented in 10 000 hectares (100 km²) in and around the Hex River Valley. The goal was to suppress, in a cost-effective and an environment-friendly manner, the Mediterranean fruit fly populations to below the economic threshold, and then create an internationally recognized low pest prevalence area (FAO 2017).

The organizational structure of this project is rather unique. It is a partnership between Infruitec/Nietvoorbij (a branch of the Agricultural Research Council (ARC), a parastatal body, with a mandate to conduct research, technology development and transfer) and the Hex River Valley Research Services Trust (which represents the deciduous fruit growers). Through an export carton levy, the growers raise funds to support programme operations (Barnes and Eyles 2000). The sterile male production, initially established by the ARC, is now managed by the private sector, and growers manage the fly release and other field operations (Venter et al. 2021).

4.5. Fruit Fly Containment Programme — Mexico and Guatemala (Box 5)

4.5.1. Problem Definition

The Mediterranean fruit fly was introduced into Costa Rica in 1955 (Enkerlin et al. 1989). It spread across Central America, causing devastating effects on fruit production, and limiting the development and growth of the fruit industry (section 2). The pest became established in Guatemala in 1976, and in 1977 was detected in the border zone between Guatemala and Mexico. By 1979, the fly had spread to the Mexican states of Chiapas and Oaxaca, beyond the coffee belt along the South Sierra Madre Mountains, and threatened the states of Campeche, Tabasco, and Veracruz. If the pest had advanced beyond the Isthmus of Tehuantepec, 600 km into Mexican territory, the USA government threatened to close its border to imported Mexican fruits and vegetables, and fly eradication would have been practically impossible (Schwarz et al. 1989).

Gutierrez (1976) estimated that preventing the establishment of the Mediterranean fruit fly in Mexico translated into annual savings of at least USD 2000 million in direct damage (including yield loss and cost of insecticide treatment) and indirect damage (including loss of the price differential obtained from selling the produce in export markets). In addition, if the pest became established, thousands of jobs across the production chain would be lost, and substantial

environmental costs would be generated by the tonnes of insecticides that would have to be sprayed to keep the pest under control.

4.5.2. *Major Achievements*

After 4 years of intensive eradication activities (1977–1982), the first programme objective was met — the Mediterranean fruit fly was eradicated from an infested area of 640 000 hectares (6400 km²) in the state of Chiapas, Mexico, using an AW-IPM approach that included legal measures (e.g. quarantine regulations), various control methods (chemical, mechanical, and cultural), and the SIT (a mass-rearing facility, producing 500 million sterile flies per week, was completed in 1979). This was the first time that a tephritid fruit fly population was eradicated at a continental level, in a region of difficult topography, high ecological diversity, and using an environment-friendly technology (Hendrichs et al. 1983).

Since eradication was achieved in 1982, for 35 years (1982–2016) the programme successfully maintained a sterile fly containment barrier. This barrier has prevented the northward spread of the pest, protecting the horticulture industries in Mexico and the USA (worth thousands of millions of dollars) (Orozco et al. 1994; Villaseñor et al. 2000; Enkerlin et al. 2015, 2017). In addition, Belize and the area of Petén (northern part of Guatemala) have been kept free of the Mediterranean fruit fly. This fly-free status has been recognized officially by the Mexican and US governments, and benefits papaya fruit growers in Petén who can now export their produce to fruit fly-free countries. The value of papaya exports to the USA in 2013 was estimated at USD 13.6 million. Moreover, other Guatemalan fly-free and low prevalence areas have been certified — Quetzaltenango, where peaches are produced commercially, and Laguna de Retana, where tomatoes and peppers are produced and exported to the USA at an estimated value in 2014 of USD 30 million.

The programme has continued to develop and adapt technologies to large-scale conditions — new and more cost-effective mass-rearing, release and field technologies for Mediterranean fruit fly control, including the temperature-sensitive lethal (*ts/l*) male-only fly strain (Cáceres et al. 2000, 2004; Franz et al., this volume), the more environment-safe insecticide spinosad (Rendón et al. 2000; USDA/APHIS/PPQ 2000), more sensitive female-biased trapping systems (Heath et al. 1995; IAEA 1999), more effective longer-lasting bait stations (Piñero et al. 2014), and more precise and intelligent chilled-adult release machines (Leal Mubarqui et al. 2014).

These technological advances, and continuing commitments from the governments of the three countries involved, have been the basis since 1999 for increased cost-effectiveness of the Mediterranean fruit fly eradication programme (Tween 2004). Moreover, it has created the basis for continuing eradication efforts in Guatemala, moving the leading edge of the infestation to the borders of El Salvador and Honduras, where the Central American isthmus starts and where the containment barrier would narrow to 50% of its current length (IICA 2013; Enkerlin et al. 2017; Rendón and Enkerlin 2021).

Box 5. Mediterranean Fruit Fly Containment Programme “Programa Moscamed”

Due to the threat that this pest posed to horticulture industries in Guatemala, Mexico, and the USA, in 1976 and 1977 the governments of the three countries, with the support of several international agencies (including the Food and Agriculture Organization of the United Nations (FAO) and the International Atomic Energy Agency (IAEA)), subscribed cooperative agreements to create the “Moscamed Programme”, a Mediterranean fruit fly programme using the SIT, with the following objectives:

- Eradicate the Mediterranean fruit fly in infested areas of the state of Chiapas, Mexico,
- Establish a containment barrier at the Mexico-Guatemala boarder, and continue eradication activities in Guatemala to create a fly-free buffer area between the containment barrier and the leading edge of the infestation in Guatemala,
- Eventually eradicate the Mediterranean fruit fly throughout Central America and Panama.

In 2015, the bilateral agreements were merged into a single Trinational Moscamed Agreement, which has strengthened the programme by facilitating harmonization of technical procedures and providing legal certainty.

4.5.3. Estimated Benefits

The primary impact of the Moscamed Programme has been to protect the expanding horticulture industries of Mexico and the USA. As a result, and under the framework of the North American Free Trade Agreement (NAFTA), Mexico’s gross revenues from horticultural products have tripled since 1994, to more than USD 9 billion per year (RIC 2017).

For Mexico, the net revenue (net present value) of the programme has been estimated at USD 39 300 million over 31 years (1978–2008), compared with the total cost of the programme in Mexico over the same period of time (estimated at USD 459 million), showing a remarkable economic return of USD 112 in crops and control costs saved for each dollar that was invested. The return is substantially higher for the USA, where the value of the fruits and vegetables that would be affected by the fly is several times higher than for Mexico. In addition, these returns are even underestimated, since no monetary value has been placed on the social and environmental savings obtained by preventing establishment of this pest.

The economic impact of the Moscamed Programme on the local economies of Chiapas (Mexico) and Guatemala has been substantial. The Moscamed Programme (which began operations in Chiapas) has permanently employed an average of 400 people (who sustain an estimated 2000 family members), apart from the hundreds that have been hired for temporary work in the factory and field operations. In 35 years, from the total programme budget, approximately USD 240 million have been spent in Chiapas, mostly for wages and the purchase of services, supplies, and equipment (Programa Moscamed 2002, 2015; IICA 2013). Moreover, maintaining the state of Chiapas free of the Mediterranean fruit fly has allowed the expansion of mango and papaya production areas and export volumes, valued at millions of US dollars per annum, and has created thousands of jobs in rural areas (IICA 2013).

Indirect benefits of the programme include:

- Strengthening the plant protection infrastructure in both Mexico and the USA, including the national and international quarantine, and national surveillance, systems — systems that protect the two countries from other exotic fruit fly pests, and also from other pests of quarantine importance that are intercepted through the same quarantine infrastructure and resources,

- Recognition of the programme, by regional and international organizations, as an International Fruit Fly Training Centre — contributing greatly to technology transfer in more than 40 countries of Latin America and other parts of the world (including the Caribbean, Africa, and Asia) through the hands-on training of hundreds of professional scientists, and
- Transfer of the SIT technology, that has been improved and validated on a large scale, to other fruit fly AW-IPM programmes integrating the SIT in other parts of the world.

Keeping Mexico and the USA free of the Mediterranean fruit fly has not only protected the horticulture industries of these countries but, for Mexico, it has also created an opportunity to develop the industry into a multimillion dollar export-oriented enterprise (Economist 2004).

4.6. *Fruit Fly Suppression/Eradication/Prevention Programme — Mexico (Box 6)*

4.6.1. *Problem Definition*

Mexico has more than 1 million hectares planted to fruit crops, with an estimated annual production value of more than USD 2500 million (SAGAR/IICA 2001). The fruit industry is significantly hindered by four fruit fly species: Mexican fruit fly, West Indian fruit fly, guava fruit fly *Anastrepha striata* Schiner, and sapote fruit fly *Anastrepha serpentina* (Wiedemann). The annual direct damage that these native fruit flies cause is more than USD 230 million (Reyes et al. 1991). This amount does not include the cost of insecticide applications, and the losses due to restrictions in fruit commercialization. These restrictions prevent the industry from benefiting from price differentials, and more importantly from market diversification, negatively affecting the general development of the industry. Some other losses are also not included, e.g. cost to human health from moderate and acute poisoning arising from applying insecticides, shortage in the supply of fruits, and negative impact on the environment.

4.6.2. *Major Achievements*

- Fruit flies of economic importance have been eradicated in more than 35 000 hectares of commercial plantations of citrus, mango, apple, and peach in north-west Mexico, completely freeing from fruit flies of economic importance the States of Chihuahua, Sonora, Baja California Norte, and Baja California Sur (SAGARPA 2001).
- In the north-east and central regions including the states of Nuevo Leon, Tamaulipas and San Luis Potosi, SIT suppression activities have reduced fruit fly populations to low-prevalence levels in parts of the more than 30 000 hectares of commercial citrus production (Orozco-Dávila et al. 2017).
- By creating federal legal instruments in support of the campaign, the construction of additional interstate quarantine checkpoints, and installation of X-ray equipment at specific ports of entry, have been possible. This has strengthened the international and national quarantine system, providing greater protection from exotic fruit flies and other pests of plants and animals.

- Mobilization and organization of fruit growers at the local level into Plant Protection Committees that link the producer associations to the plant protection activities at the state and federal government levels.
- Through training courses and workshops, a work force of hundreds of professional scientists, specialized in the large-scale and area-wide operation of phytosanitary campaigns, has been deployed throughout the country.

Box 6. Mexico National Campaign against Anastrepha Fruit Flies

Anastrepha spp. fruit flies are major horticultural pests in Mexico. After a thorough economic feasibility study (Reyes et al. 1991), in which the returns of integrating the SIT into the control of fruit flies in major commercial fruit production areas were assessed, the Mexican federal government in 1992 approved the National Fruit Fly Campaign (Campaña Nacional Contra Moscas de la Fruta (CNCMF)), with the following objectives:

- To suppress, and in selected areas eradicate, fruit flies of economic importance in fruit production areas, using an AW-IPM approach including the SIT.
- To protect Mexico from the introduction and establishment of other economic fruit fly species that threaten the country.

The CNCMF is part of the Plant Protection General Directorate of the Ministry of Agriculture, Livestock and Rural Development (SAGARPA). The CNCMF operates through state governments and fruit-grower associations under compliance agreements subscribed to by the three parties (federal and state governments, and fruit industry).

The resources required to operate the programme are contributed in equal parts by the federal and state governments and the fruit industry, in financial and in-kind contributions. The federal government facilitates the legal instruments for smooth implementation of the programme, supplies the sterile flies, and operates international quarantine stations at ports of entry. The state governments, through their plant protection infrastructure, are responsible for distributing and releasing the sterile flies, and for conducting field activities outside the fruit production areas to assure area-wide control of the pests. Responsibilities also include operating quarantine interstate road stations. At the farm level, the programme is conducted by the fruit industry, through Plant Protection Committees, that link the producer associations with the state and federal governments. Activities of producers in orchards include trapping, applying bait sprays, and releasing sterile flies (Reyes et al. 2000).

4.6.3. Estimated Benefits

In the first 4 years after 1997, when fruit fly eradication in north-west Mexico was officially declared, the direct benefits (reduced fruit fly damage and increased yield) amounted to USD 25 million. In addition, in the same time period, the benefits obtained from the price differential paid by export markets, and savings in postharvest treatments, totalled approximately USD 35 million. Thus, the total benefits in these fruit fly-free areas over 4 years amounted to USD 60 million, with a total cost of USD 4 million over the same time period, resulting in a BCR of 7.5 to 1 (SAGAR/IICA 2001).

A retrospective economic assessment was conducted to estimate the return on investment of the National Fruit Fly Campaign, specifically for mango and citrus, two of the mayor fruit crops produced in Mexico that are affected by fruit fly pests. Results indicated a BCR of 22 for mango and of 19 for citrus, clearly justifying the investment on fruit fly control done by the Mexican Federal Government and the fruit growers (IICA 2010).

The eradication of fruit flies, and subsequent international recognition and maintenance of the fruit fly-free status, permitted an expansion of the area planted to fruit crops in the north-western states to 50 000 hectares. No doubt this has resulted in substantial economic and social benefits to that region of Mexico.

4.7. Other Successful Programmes

Section 4 describes examples of programmes that have produced substantial economic returns after applying area-wide SIT against fruit fly pests; economic assessments or detailed quantification of costs and benefits are available for these programmes. However, there are other successful programmes for which detailed economic assessments have not yet been done, but that have also generated substantial benefits. One of these programmes is the SENASA Fruit Fly Control Programme in Peru, where in 2008 the eradication of the Mediterranean fruit fly and *Anastrepha* fruit flies from the regions of Tacna and Moquegua, integrating the SIT, was declared officially. This was achieved through a joint venture of the Peruvian State, producers, exporters, and regional and local authorities; financial support was also obtained from the Inter-American Development Bank, and technical and financial support from the FAO and IAEA. Programme achievements included: avoiding annual losses of more than USD 12 million in the production of fruits and vegetables, generating direct benefits to 17 876 producers in approximately 38 000 ha, avoiding annual use of over 600 000 litres of insecticides, helping to preserve the environment, and creating opportunities for the national and international trade of horticultural products within the framework of trade agreements with the USA (FAO/IAEA 2008).

Another successful programme is the Moscamed Programme in the Dominican Republic. A large Mediterranean fruit fly outbreak, covering an area of 2000 km², occurred in March 2015 in the eastern part of the country. In only 10 months, USD 40 million was lost because of quarantine restrictions on exports of host commodities including tomatoes, bell peppers, and avocados. Eradication was achieved after two years of intensive area-wide integrated pest management including pest monitoring, population suppression using ground and aerial bait sprays and bait stations, and eradication using the SIT. Eradication was declared officially by the Ministry of Agriculture in July 2017; net revenues from fruit and vegetable exports have since been re-established. Eradication of the Mediterranean fruit fly benefited the Dominican Republic, and also protected the horticultural industries in the Caribbean region and in neighbouring countries including the USA and Mexico (FAO/IAEA 2017; Gil 2017; Zavala-López et al. 2021).

5. SUMMARY OF ECONOMIC RETURNS

The BCR achieved in some major fruit fly AW-IPM programmes integrating the SIT is high, ranging from 2.8 to 1000, clearly showing that the SIT technology, when properly integrated with other methods and applied on an area-wide basis, is feasible and economically viable (Table 2). Even when the types of benefits accrued from these programmes are similar, the returns on investment (BCR) vary widely, even among programmes with common fruit fly pest problems and similar strategic objectives. This is due to the different intrinsic characteristics of each programme, e.g. the magnitude of the pest damage, size and value of the crops being protected, targeted markets, commitment of the main stakeholders, resources available to execute the programme, and efficiency in programme management.

6. CONCLUSIONS

The high economic returns from some fruit fly AW-IPM programmes that integrate the SIT are possible primarily because of the environment-friendly and area-wide nature of the SIT technology. This technology allows cost-effective suppression, and in selected cases eradication, of insect pest populations, and also prevents the establishment of important fruit fly species in pest free areas through the use of pest risk-mitigation measures, such as SIT containment and prevention programmes. Such programmes protect, at a relatively low cost, high-value horticulture industries, such as those in Argentina, Australia, Chile, Mexico, and the USA. This is a major advantage of the SIT technology when compared with more conventional pest control methods such as insecticides (Enkerlin 2003). In contrast, the worldwide BCR of insecticides has been estimated at 4:1, if indirect costs are excluded, and only a 2:1 ratio if indirect environmental and public health costs are included (Pimentel 1991). As the use of the SIT technology for certain pests and crops expands, with increasing cost-effectiveness at economies of scale, it is expected that the release of sterile insects will gradually reduce the application of insecticides. The insecticide industry is gradually viewing the SIT as an opportunity for diversification rather than as a competing technology; this has already happened with other control methods that are biological in nature.

One of the unique features of the integrated application of the SIT is that, since its application is area-wide, the benefits spread beyond commercial fruit and vegetable producers to backyard gardens and subsistence farms in poor rural areas. In the future, the SIT will contribute even more to improved food security worldwide by increasing fruit and vegetable production in a cost-effective, environmentally clean, and sustainable manner.

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Table 2. Estimated Costs, Benefits, and Benefit/Cost Ratios (BCR) for some Major Fruit Fly AW-IPM Programmes Integrating the SIT

Programme	Parameter used to measure benefits	Average annual cost ¹ (USD million)	Average annual benefit (USD million)	Benefit/cost ratio (BCR) ²	References
Mediterranean Fruit Fly Containment Programme “Programa Moscamed”	Protection of horticulture industry in Mexico (includes only investment by Mexico and potential production losses and costs, and market loss)	14.8	1660	112	Gutierrez 1976; Reyes et al. 1991; IICA 2009, 2013
Melon Fly Eradication Programme in Okinawa, Japan	Export of fruit commodities (mainly mango and bitter melon) after eradication was achieved	7.7	41.7	5.4	Kakazu 2002
National Mediterranean Fruit Fly Control Programme in Chile	Export of horticultural products affected by fruit flies	4	4000	1000	MAG/SAG 1995; Lindquist and Enkerlin 2000; ASOEX 2017
Hex Valley Mediterranean Fruit Fly Suppression Programme in South Africa	Savings in chemical sprays and table-grape rejections during the certification process	0.13	0.37	2.8	IAEA 2002
Mexico National <i>Anastrepha</i> Fruit Fly Campaign	Savings in direct damage and value of fruit exports from the fly-free areas in north-west Mexico	32	772	24	IICA 2010
Mediterranean Fruit Fly Preventive Release Programme in Los Angeles Basin, California, USA	Protection of California’s horticulture industry from yield loss in agriculture and home-garden production, increased insecticide use, loss of export markets, and annual quarantine compliance cost	15	1300–1900	87–127	CDFA 2002
Control of the Mediterranean Fruit Fly in Israel/Jordan	Export of vegetables from the Arava Valley	0.8	8	10	Cayol et al. 2004

¹Includes fixed and variable operational costs, but not capital or financial costs.

²Assuming the whole benefit is lost in the event of fruit fly establishment and widespread infestation.

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