Pulling Out the Evil by the Root: the Codling Moth *Cydia pomonella* Eradication Programme in Brazil

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ABSTRACT Since the codling moth *Cydia pomonella* (L.) was detected in parts of the Brazilian apple growing area a series of surveillance and control actions have been carried out. Firstly, a trapping survey determined the extent to which the pest had spread in Brazil. Pheromone traps were set up and serviced during one season throughout the temperate fruit growing region, at ports of entry and in the main southern commercial centres (São Paulo, Florianópolis, Santos, Curitiba). This trapping demonstrated that only urban areas within four municipalities were affected: Vacaria, Bom Jesus, Caxias do Sul and Lages. Except for the last, the affected municipalities are important apple growing regions, with more than 3000 hectares of apples each. In 1998/1999, a pilot project of population suppression was undertaken in these affected areas, applying lure-and-kill (male annihilation). This technique proved to be highly efficient in reducing codling moth populations. Results encouraged the elaboration of a series of scientific projects and the development of a plan to eradicate the codling moth from Brazil. The programme has several components: (1) commercial apple orchards adopted detection trapping to identify any new invasion event, (2) removal of host and potential host trees in urban areas and replacement by non-host trees in many cases adopted as an alternative to direct population suppression in the urban areas, and (3) the potential use of the sterile insect technique (SIT) in certain areas. The host tree removal campaign led to a significant decrease in codling moth populations as evidenced by the decrease in the number of catches in pheromone-baited traps used for monitoring. The main constraints to the development of the eradication programme were bureaucratic and legislative. Lack of funds and of national legislation on semiochemicals jeopardized effective actions. In this report, updated data are presented on codling moth population dynamics in four infested areas as well as an overall evaluation of the survey and control activities carried out thus far.

KEY WORDS *Cydia pomonella*, codling moth, SIT, host availability, lure-and-kill, eradication, Brazil, apple, host removal, biological invasion

1. Historical Background

The codling moth *Cydia pomonella* (L.) is a quarantine pest of apples in Brazil. Given its importance in other apple growing countries, efforts to monitor for possible incursions started in the 1980s, using a few traps which invariably returned zero catches. In 1991, a single pheromone-baited trap was deployed in a domestic orchard in the urban area of Vacaria, Rio Grande do Sul. One male codling moth was caught and again in 1992, two males were trapped at the same location.

In January 1993, traps were set up in other municipalities near Vacaria, but no moths were trapped. At that time, pheromone traps were not available in Brazil and had to be imported from Chile. Only in 1997-1998 did traps become available and could be deployed at the appropriate time of the season, in early September.

The programme faced several early obstacles, such as lack of understanding about the importance of preventing the colonization and

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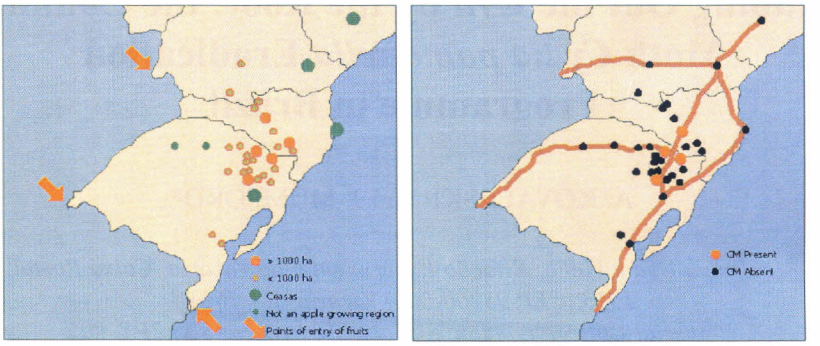

Figure 1. *Delimiting survey of* Cydia pomonella *in the three southern states of Brazil and São Paulo. (left) Municipalities where traps were deployed indicating major apple growing regions (red circles), minor apple growing areas (green circles) and points of entry of fresh fruits from Uruguay, Argentina and Chile (arrows), and (right) uninfested (black circles) and infested municipalities (red circles).*

spread of a new apple pest in Brazil. This was turned around by the dynamism of apple growers who, aware of the importance of the codling moth in other countries, provided financial support to official actions to prevent its establishment. The plant protection actions of the Ministry of Agriculture were improved, and the inspection of imported temperate fruits became routine at all ports of entry.

Now, 15 years after the first detection of *C. pomonella* in Brazil, the programme is quoted throughout the country as an example to be followed with researchers, control officials and growers joining efforts to prevent the establishment and spread of a new pest. This paper presents an overview of the codling moth control programme in Brazil since detection of the pest in the urban area of Bom Jesus, as well as forthcoming activities.

2. Detection Trapping

Detection trapping was initiated during the 1980s, with a few traps baited with codling

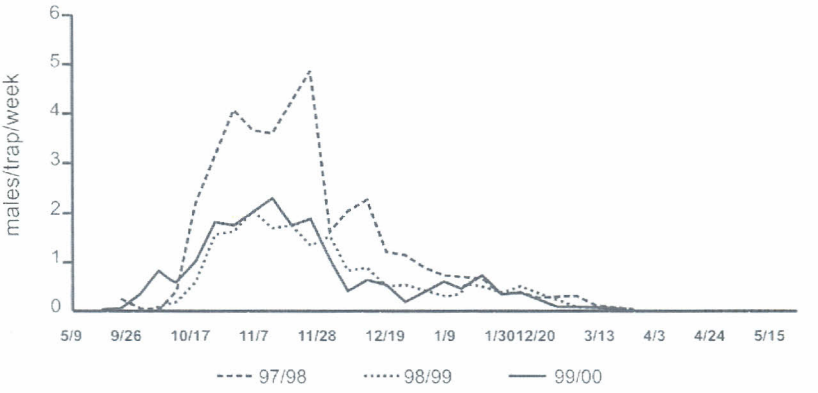

Figure 2. *Population dynamics of the codling moth in Lages, Santa Caterina, Brazil, as indicated by weekly male catches in pheromone-baited traps (1997-2000).*

Table 1. *Number of traps deployed in the urban areas of the four municipalities affected by the codling moth in Brazil.*

Period	Vacaria	Lages	Bom Jesus	Caxias do Sul
1998/1999 to 2003/2004	400[1]	400	100[1]	180[1]
2004/2005	400	1700	200	400
2005/2006	1100	1700	400	550

[1]Incomplete data due to lack of traps in some years

moth sex pheromone. The first male was caught in October 1991. Another two males were caught in the same domestic orchard in October 1992. In January 1993, the number of traps was increased to 32 but no males were caught. In 1994-1995, a network of detection traps was deployed in the field, ranging from the southernmost region of the country to São Paulo (Fig. 1).

Four municipalities were defined as affected: three in the state of Rio Grande do Sul (Vacaria, Bom Jesus and Caxias do Sul) and one in the state of Santa Catarina (Lages). Monitoring in urban areas of affected municipalities was carried out with synthetic pheromone-baited traps (Table 1).

With the establishment of integrated fruit production, detection trapping was adopted as an obligatory action throughout the 30 000 hectares of commercial apple production. Growers are in charge of trap deployment and service and they receive training on codling moth identification. They are also instructed to bring to Embrapa Uva e Vinho, in Vacaria, any trapped individuals that may resemble the codling moth.

In commercial areas located less than 30 kilometres from urban areas where the codling moth was detected, a density of one trap per five hectares is adopted. In other areas the recommendation is one trap per ten hectares. To date, there are no records of codling moth males being trapped in Brazilian commercial apple orchards. Inspection procedures are submitted to external audits by the Plant Protection Service in the states of Santa Catarina and Rio Grande do Sul.

3. Population Dynamics

In Brazil, adult codling moths are first trapped in September and the population peaks from late October to mid December. Laboratory observations corroborate these data on the onset and peak of adult emergence and also indicate that 95% of field-collected larvae enter diapause which may last for up to two years (Fig. 2).

This univoltine pattern differs from that described in other South American countries, where the pest is bivoltine. A possible explanation is the shorter photoperiod during summer, due to the lower latitude of the Brazilian apple growing area compared with more southerly regions in South America. Thus, regardless of the adopted methodology an eradication programme should concentrate actions from October to January.

4. Lure-and-Kill Pilot Project

The delimiting survey demonstrated that the codling moth was restricted to four urban areas. The use of chemical control was deemed unacceptable due to the potential hazard it could present. There were few alternatives: the sterile insect technique was not available in Brazil, nor were pheromone-based techniques due to lack of registered materials.

Brazil did not have a specific legislation for pheromones and their registration had to follow the same procedures adopted for pesticides. However, in 1998, the Ministry of Agriculture of Brazil responded to the prob-

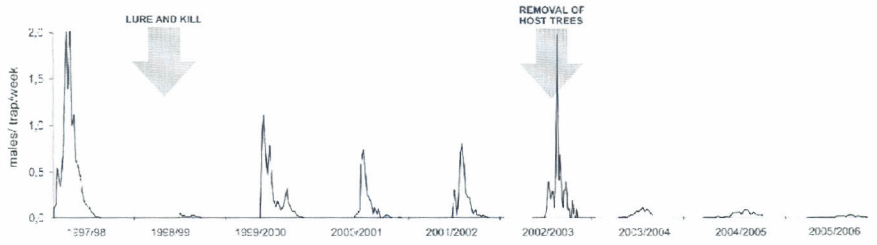

Figure 3. Cydia pomonella *population density in the urban area of Vacaria, Rio Grande do Sul, Brazil, 1997-2006 as revealed through trap catches. In 1998-1999, lure-and-kill was applied throughout the urban area and partially in 2000-2001. In 2002-2003 host plant replacement was initiated and in 2005-2006, only 0.6% of the original host plants remained in the urban area.*

lem and allowed an urgent importation of pheromone dispensers which were used to attract males to paper panels impregnated with naled, an organophosphate with long residual effect.

The technique was applied throughout the urban areas of Vacaria and Bom Jesus and in part of the urban area of Lages. Results were immediately positive and promising. In 1998-1999, the population density of *C. pomonella* in Vacaria and Bom Jesus was reduced to less than 5% of that observed in 1997-1998. Nevertheless, in 1999-2000, there were neither funds nor pheromone dispensers available and the control operations could not be continued. The codling moth population density increased in that season, although not to the levels observed in 1997-1998, but it was clear that lure-and-kill itself would not be sufficient to prevent further population build up. Lure-and-kill was applied a second time in Vacaria during 2000-2001 and in Bom Jesus in 2003-2004 in those locations identified as having high infestation levels. Difficulties in registration of pheromone-based techniques and high costs led the working group involved in the programme to focus on a second technique, the removal and replacement of host plants from urban areas.

5. Host Plant Replacement

It was hypothesized that the elimination of host plants from urban areas would reduce the codling moth population. Activities were started in Lages in 2001 and in Vacaria in

Table 2. *Number of host plants and potential host plants removed and the estimated number remaining in the urban areas of the four affected municipalities.*

Municipality	Urban area (hectares)[1]	Trees replaced (no.)	Trees remaining (no.)	Trees removed (%)
Lages	12 000	34 500	200	99.4
Vacaria	6000	16 020	600	96.4
Bom Jesus	1000	1700	300	85.0
Caxias do Sul	60 000	37 609	22 391	62.7
Total		89 829	23 491	86.9

[1]Approximate values

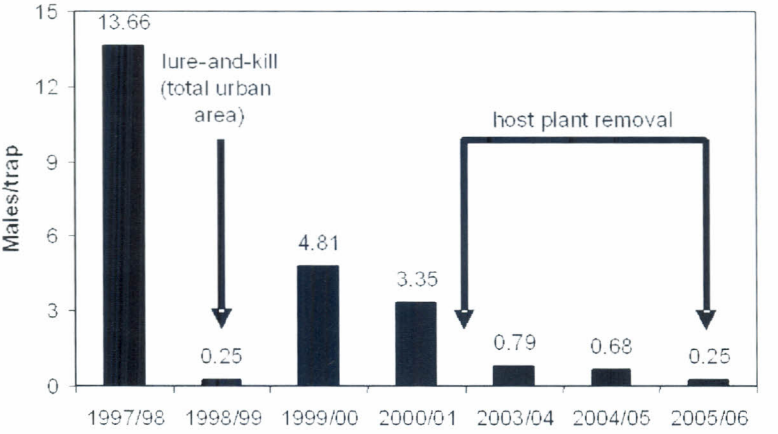

Figure 4. *Number of codling moth males per trap from 1997-1998 to 2005-2006 in Vacaria. Few traps were used for monitoring in 2001-2002 and 2002-2003. For this reason, data are not included in this graph.*

2002. In Vacaria, the replacement of host plants occurred centripetally to avoid the dispersal of codling moth from the urban area to orchards located nearby. In both areas, the work was supported by apple growers and the Ministry of Agriculture of Brazil, with both groups allocating personnel, funds, and equipment to the campaign mainly during the apple off-season. The number of trees removed and replaced and the estimated number of remaining trees is summarized in Table 2.

At this point the cooperation of mass-communication media such as local radio stations and newspapers was crucial for the success of the campaign. Residents became aware of the importance of the apple crop in nearby areas and of the negative impact that codling moth establishment would have on the economy of the region.

The impact of host removal on trap catches was immediate and long-lasting. Taking Vacaria as an example, after the onset of actions to eradicate host plants in 2002, the highest codling moth population density

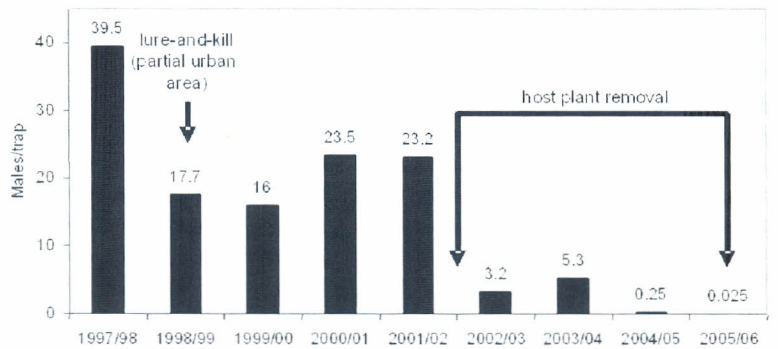

Figure 5. *Number of codling moth males per trap from 1997-1998 to 2005-2006 in Lages.*

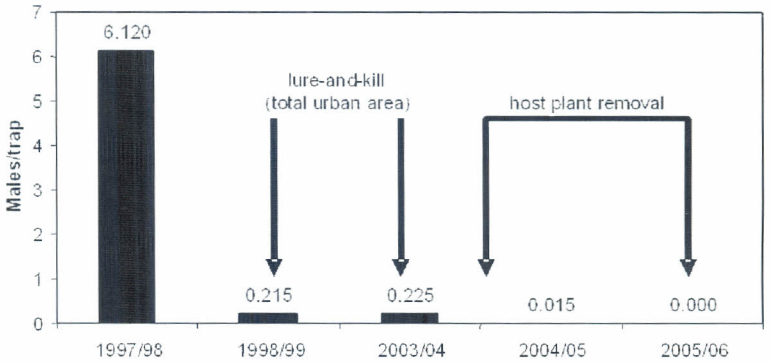

Figure 6. *Number of codling moth males per trap from 1997-1998 to 1998-1999 and from 2003-2004 to 2005-2006 in Bom Jesus.*

decreased from approximately two males per trap per week in 1997-1998 to 0.02 males per trap per week in 2005-2006 (Fig. 3). Similar results were observed in Bom Jesus, Lages and Caxias do Sul (see section 6).

6. Monitoring

Monitoring in commercial and urban areas of the temperate fruit growing region of Brazil had been conducted since the early 1990s, but 1997-1998 can be considered as the starting point of systematic monitoring.

The four areas showed different population densities at the beginning of the systematic monitoring in 1997 (Figs. 4-7). In 1998-1999, lure-and-kill was applied in the urban areas of Vacaria, Bom Jesus and Lages. In Vacaria, 20 000 killing panels were set up in the urban area. These inverted V-shaped panels had an internal surface covered with stick. The paper panel and adhesive surface were dipped in an organophosphate insecticide. After insecticide impregnation, a pheromone dispenser was attached to the system with a pin. The impact of lure-and-kill during the 1998-1999 season was clear: the codling moth population was reduced to almost undetectable levels. It is reasonable to suppose also that monitoring traps may have been affected by the presence of a large number of pheromone dispensers in killing panels. In the three subsequent seasons (September 1999 to March 2002), the population density increased following the suspension of lure-and-kill actions. During the spring of 2002, host trees were replaced by non-host trees in the urban area of Vacaria. The impact of this action was promptly realized in greatly reduced trap catches in subsequent years (Fig. 4).

Lages had the highest initial codling moth density, with almost 40 males per trap during the 1997-1998 season (Fig. 5). A partial application of lure-and-kill was accomplished in 1998-1999 but the population density was high during the next five seasons of monitoring, with mean densities close to or higher than 20 males per trap. In 2003, almost 30 000 host plants were replaced by non-host trees in Lages. As was observed in Vacaria, this action had a profound impact on the population, with a marked reduction in abundance.

In Bom Jesus, Rio Grande do Sul, lure-and-kill was applied during the spring of 1998-1999. Trapping data show that although the population density at the beginning of the programme was very high it was reduced to almost undetectable levels in 2004-2005 and to zero in 2005-2006 (Fig. 6).

During the same period, the codling moth was monitored in Caxias do Sul, Rio Grande do Sul. In this municipality, suppression actions were not undertaken until 2004-2005 when host tree removal was initiated. Actions

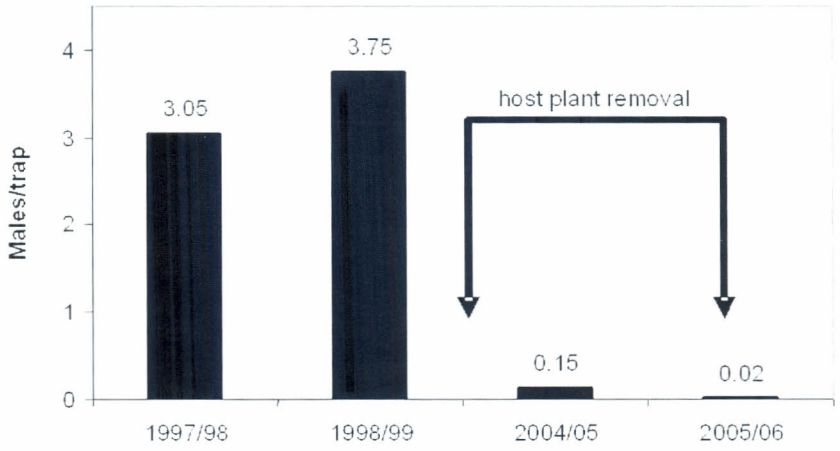

***Figure** 7. Number of male codling moths per trap from 1997-1998 to 1998-1999 and from 2004-2005 to 2005-2006 in Caxias do Sul.*

in Caxias do Sul were delayed because it is a much larger urban area and the fact that agriculture plays a much less important role in the economy of the municipality. In 2005-2006, the population density was markedly reduced (Fig. 7). Here, since a significant proportion of city residents did not agree with the replacement of host plants, other techniques may have to be employed to ensure eradication, such as the SIT.

7. External Quarantine Actions

In 2004, after several meetings involving the Brazilian and Argentinean plant protection agencies, an inspection protocol was implemented in the packinghouses in Argentina that market fresh apples and pears to Brazil. They had to be able to demonstrate that fruits originated from areas of low codling moth prevalence or, in cases in which they did not, that growers had adopted effective control methods. This decreases the risk of new invasion events as Argentina is the main supplier of fresh pears to Brazil. Also, an inspection routine of pome and stone fruit shipments from all other countries was established at borders, airports and ports.

8. Benefit/Cost Analysis

The first assessment of benefits and costs associated with *C. pomonella* eradication in Brazil indicated that if the no action scenario was chosen, the codling moth would become established in commercial orchards and lead to control costs much higher than those estimated for an eradication programme based on host plant replacement and lure-and-kill (Kovaleski et al. 2001).

A spreadsheet model was produced by Mumford (2005) to provide a basis for a benefit/cost analysis for codling moth eradication in Brazil based on data from Kovaleski et al. (2005) and interviews with growers and officials involved in the monitoring and eradication. The model is a stochastic simulation model based on best estimates of parameters likely to affect the values of production and control of codling moth host crops (apple, pear and quince) in the three southern states of Brazil, and the options and costs of eradication in the four affected urban areas in Brazil. Fig. 8 illustrates an output. The potential losses to the fruit industry in Brazil if eradication or containment is not achieved in the urban areas are very significant, with an estimated

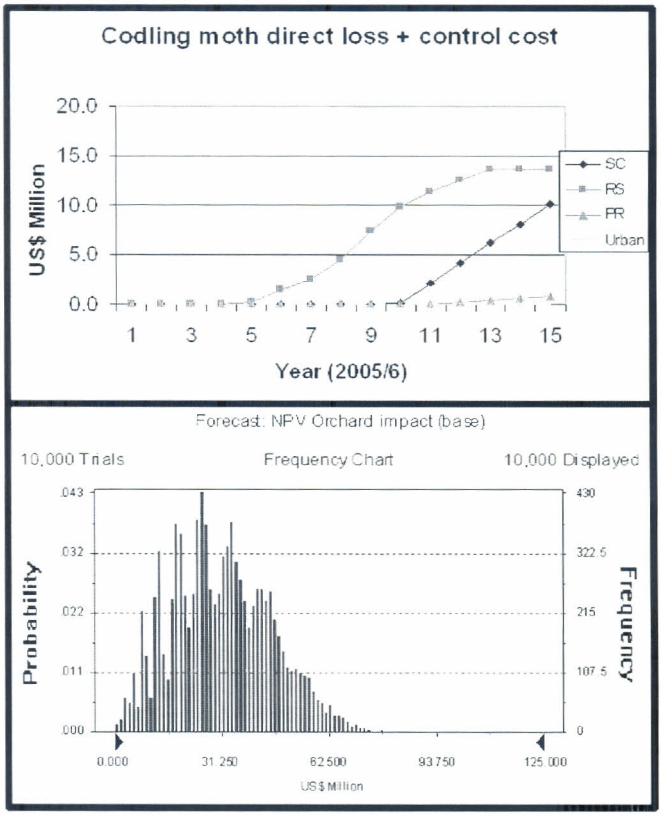

Figure 8. *(upper) An example simulation iteration for spread beginning around five years from present (SC: Santa Catarina, RS: Rio Grande do Sul, PR: Paraná), and (lower) the frequency distribution of net present values (NPV) of commercial losses over 15 years at 10% discount rate (adapted from Mumford (2005)).*

net present value (over 15 years) for losses and costs of up to USD 113 million.

The pathways for reinvasion from Argentina have been eliminated to the degree practical through border quarantine and packing house inspections for Argentine apple exports. Intensive monitoring has shown no spread to commercial orchards in 15 years of infestation in four urban areas of Brazil. Substantial progress has been made in two of the urban areas to remove host trees. Eradication appears to be technically feasible, with further host tree removal and replacement, lure-and-kill in areas with small numbers of remaining host trees (less than 5%) and SIT in areas with over 5% of remaining host trees. It was estimated that the cost of eradication, assuming spread into orchard areas did not occur for 3-7 years, would range from USD 0.286 million to USD 0.644 million, with a mean of USD 0.452 million (Mumford 2005). If SIT were used for the control of codling moth in the four infested areas of Brazil, it is estimated that the numbers of sterile moths required would range from 1-1.5 million per week considering that releases would be directed only against relic moths. This assumes two years of further host

tree removal and concentration of the infestations within the smallest areas of highest host density. Under these scenarios, no infestations or costs occur in commercial orchards. However, without further host tree removal the likelihood of spread into commercial orchards is significant. Under this scenario, costs range from a minimum over USD 0.8 million (in simulations with no spread to commercial orchards), to a mean of around USD 1.5 million (with some impact on commercial orchards), and a maximum cost of over USD 100 million in simulations with extensive infestations occurring in commercial orchards (Mumford 2005).

9. Conclusions

The codling moth is both an interesting issue for scientific investigation in the field of invasion biology and a unique opportunity for plant protection agencies to take action to prevent establishment of a significant new pest. Results obtained thus far are promising and apple growers have agreed to continue investing in codling moth eradication, so as to declare Brazil a codling moth-free country like Japan. Much practical work was necessary, with many setbacks, to secure the credibility of an eradication programme in the eyes of growers and technicians. This is particularly difficult in a country like Brazil with a limited tradition in plant protection. Fortunately, growers are organized in associations and are aware of the direct and indirect costs that the establishment of a new pest would cause them. Currently, the codling moth eradication programme is a major concern for growers. It has been demonstrated that eradication is technically feasible and cost-effective. The increase in the trapping effort in urban areas aims to define hot spots clearly and rapidly. The next step will be the application of the SIT, mainly in Caxias do Sul, an industrial municipality where the eradication programme has been facing difficulties. An analysis of the technical and economic feasibility of importing sterile males from the Okanagan-Kootenay Sterile Insect Release mass-rearing facility in Osoyoos, Canada will be undertaken. Costs and benefits associated with the importation of sterile insects will be compared with those associated with establishing a mass-rearing facility in Juazeiro, Brazil (Malavasi et al., this volume).

10. Acknowledgements

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