AREA-WIDE MANAGEMENT OF FRUIT FLIES IN A TROPICAL MANGO GROWING AREA INTEGRATING THE STERILE INSECT TECHNIQUE AND BIOLOGICAL CONTROL: FROM A RESEARCH TO AN OPERATIONAL PROGRAMME

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SUMMARY

The Sterile Insect Technique (SIT) has been successfully used for the control of fruit flies in a number of places in the world. One requirement for its successful application is that wild populations should be at low densities to achieve effective sterile to wild fly overflooding ratios. This has been an important reason that has limited its integration in fruit fly management in tropical fruit growing areas, where climate conditions and the availability of hosts all year-round results in high population densities. Here we report the results of a project where SIT integration into fruit fly management was evaluated under the tropical conditions of the mango growing area in the Soconusco region of Chiapas, Mexico. The basis for the area-wide integrated pest management (AW-IPM) approach was the knowledge of the population dynamics of the pest fruit flies in the region and of the fruit phenology. The main commercial mango growing areas are in the lowlands, where fruit fly populations are very low outside of the mango production season. Population densities are higher in the midlands and highlands, where alternate hosts are common in backyards and as part of the natural vegetation. We call these refuge areas, and the AW-IPM approach aimed at establishing a biological barrier with releases of parasitoids and sterile male fruit flies to suppress the fruit fly populations and prevent or minimize the dispersal of wild flies from the refuge areas to the mango orchards. In 2014, after two years of releases, fruit fly population densities were suppressed more than 70% in the release area and 65% in the entire area, including the lowlands with the mango orchards. With the support of fruit growers, state and federal governments, this project was continued and established as an operational AW-IPM programme. In 2016, after 4 years of programme implementation, the detection of wild flies was significantly reduced, and the number of batches of fruit that were rejected at the packing houses due to the detection of infested fruits was the lowest in the past 12 years, since the recording of these data was initiated. These indicators declined even further in 2017. The results obtained demonstrate that AW-IPM integrating the SIT can be applied successfully against fruit flies under tropical conditions with naturally high pest densities, providing there is adequate knowledge on the population dynamics of the fruit fly species present in the region.

Key Words: Integrated pest management, autocidal control, SIT, augmentative biological control, *Anastrepha* fruit flies, Tephritidae, *Anastrepha ludens*, *Anastrepha obliqua*, *Diachasmimorpha longicaudata*, Soconusco, Chiapas, Mexico

1. INTRODUCTION

In Mexico, mango represents one of the most important fruit production and export value chains, with more than 180 000 ha of cultivation, giving an annual production of approximately 1.8 million tons. Mexico ranks 6th by area and 4th by production in the world, and on the international market Mexico and India are among the most important exporting countries by volume (SIAP 2015).

Among the factors that limit or affect mango production and marketing are insect pests, and within these, fruit flies are among the most devastating. In view of their importance, these are considered of public interest and for this reason the National Campaign against Fruit Flies was established in 1992. The Campaign has succeeded in achieving fruit fly pest free areas (FF-PFA, FAO 2016) in 52.8% of the national territory, and fruit fly areas of low pest prevalence (FF-ALPP, FAO 2008) in another 10.4%, while the remaining 36.8% is considered a zone under phytosanitary management (Liedo 2016; Ramírez y Ramírez et al. 2019). Due to their agro-ecological requirements, mango producing areas are located mostly in the subtropical and tropical zones of the country, most of which are in the area under phytosanitary management. Under these favourable ecological conditions that promote fruit fly abundance, the development of technologies and the design of pest management strategies are required to allow the production of fruits free of fruit fly damage.

There are modern and appropriate and more sustainable technologies to deal with these pests, such as the Augmentative Biological Control (ABC) and the Sterile Insect Technique (SIT), among others (Montoya and Toledo 2010; Enkerlin et al. 2021). These technologies, integrated with other control methods have been applied successfully in Mexico to prevent for over 35 years the invasion of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), into southern Mexico along the border with Guatemala (Enkerlin et al. 2015) and for the implementation of FF-PFA for native *Anastrepha* fruit flies in the north of the country (Reyes et al. 2000; Liedo 2016). However, under the tropical conditions in which commercial mango is extensively grown, native *Anastrepha* fruit flies have high rates of population growth and therefore the effective application of these technologies is much more challenging (Montoya et al. 2000).

The characteristics of the SIT and the ABC, as well as the high mobility of fruit flies, make it necessary to adopt an area-wide integrated pest management (AW-IPM) approach, which considers the management of the total population of the pest and its spatial distribution (Hendrichs et al. 2007; Montoya et al. 2007).

In the mango producing region of Soconusco, Chiapas in southern Mexico, there is ample knowledge about the population dynamics of *Anastrepha* fruit flies (Aluja et al. 1996; Celedonio-Hurtado et al. 1995; Montoya et al. 2000). In the case of *Anastrepha ludens* (Loew) and *Anastrepha obliqua* (Macquart), which are the species that infest mango, it is known that their populations are high in the midlands and in the highlands (120-600 m elevation) with little temporal fluctuations.

In the commercial mango production areas of the lowlands (0-120 m elevation), the *Anastrepha* populations are low most of the year and only increase during the mango fruiting season, when growers have to apply repeated ground bait sprays to minimize fruit fly infestation.

Based on the available background information, and with the objective to reduce the bait sprays and fruit fly infestation in mangoes, a project was submitted to validate the use of the ABC and the SIT as elements of an AW-IPM approach, for the management of these native fruit flies in mango. We proposed to carry out this project in the Soconusco region in Chiapas State, considering the available knowledge on fruit fly populations, their hosts and their seasonality, and taking advantage of the infrastructure of the National Fruit Fly Campaign (Mexican Plant Protection Organization SENASICA, and IICA) in the region with respect to mass-rearing and release of sterile fruit flies and parasitoids. This 4-year project was funded by the National Council of Science and Technology (CONACYT) and the Ministry of Agriculture (SAGARPA) sectorial fund. In view of the increasing support and interest of the mango growers, the project was converted into an operational programme during the fourth and last year of the project.

2. MATERIALS AND METHODS

2.1. Strategy

It was assumed that the *Anastrepha* populations are maintained by year-round host availability in the refuge sites of the midlands and highlands outside the mango season. Thus, the designed strategy consisted of implementing a "biological barrier" based on the release of sterile flies and parasitoids in the intermediate zone between the high and the lowlands (ca. 100-200 m elevation), seeking to suppress the populations there and avoiding or minimizing their movement to the lowlands, where most of the commercial mango orchards are located. To facilitate achieving favourable sterile to fertile male ratios, releases of sterile insects were initiated at the end of November or early December 2012 and continued to 2015, i.e. the period when historically the lowest population levels have been observed (Aluja et al. 1996).

In the first year of the project (2011-2012), two trapping transects were established from the highlands to the lowlands, to monitor the populations of fruit flies along an altitudinal gradient (Fig. 1). Before initiating the releases in the second year, a third trapping route was established with the objective of monitoring the populations of sterile flies in the release polygon and adjacent areas.

The initial experimental design for the 4-year project (2011-2015) was: (a) to monitor populations during the first year without the application of the ABC and the SIT, (b) to apply the ABC and the SIT in the intermediate zone during the second and third years, and (c) depending on results, to transfer the technology to mango growers during the fourth year. Based on the results obtained during the second and third years, when the control methods were applied on an area-wide basis, it was decided to continue with the releases for another year. During this fourth year, the technology was transferred, and from week 10 of 2015, the fruit growers' union was in charge of

funding and coordinating the parasitoid and sterile fruit fly releases through the Local Board of Plant Health and the State Committee of Plant Health of Chiapas. During this fourth year, the research project was converted into an operational action programme, recognized by the National Fruit Fly Campaign.

Based on the monitoring of the first year and the availability of biological material, a 15 000 ha polygon (21.0 x 7.14 km) was established for the release of parasitoids and sterile fruit flies. This polygon was located between the cities of Mazatán and Tapachula, in the transition zone between the high and the lowlands. The location of the release polygon and the traps deployed are shown in Fig. 1.

Figure 1. Location of the sterile fly release polygon in the Soconusco region of the state of Chiapas, covering 15 000 ha, and the three subquadrants for the release and assessment of parasitoids of 5000 ha each, as well as the location of the traps for population monitoring.

The blue dots indicate the location of the traps deployed along transect 1, the red dots correspond to transect 2, and the yellow dots to transect 3.

For the evaluation of the ABC, the polygon was subdivided into 3 quadrants of 5000 ha each in which to make and assess the release of parasitoids. Initially, it was planned to release the parasitoids only in the sub-quadrant to the East -the one with higher trap captures- and leave the central one as the buffer area and the one on the West as a control, with the intention of alternating the quadrants in the third year and thus be able to make comparisons in time and space. However, based on the results obtained in the second year, it was decided to repeat the release area in the third year (East quadrant) in order to evaluate the effect of the modifications in the release method (see below) and also to contribute to the suppression of pest populations in the area of highest infestation.

2.2. Monitoring of Populations

For the monitoring of the *Anastrepha* populations, Multilure® traps baited with Biolure® (ammonium acetate + putrescine) were used. Propylene glycol was used for the retention and conservation of the trapped specimen. The traps were checked weekly and the trapped flies identified by species and sex. In the case of *A. ludens* and *A. obliqua*, the dye marking used for the sterile flies was used to discriminate between the released sterile and wild flies. Along transect 1, 35 traps were deployed from the town of Huehuetán in the highlands to Barra de San Simón in the lowlands. Forty-four traps were deployed along transect 2 from Canton Pumpuapa to the northwest of the city of Tapachula, in the highlands, to the Ejido Conquista Campesina, in the lowlands. Transect 3 contained 30 traps of which 15 were deployed within the release polygon, 10 were located in the area adjacent to the north of the polygon and another 5 to the south of it (Fig. 1).

2.3. Biological Material

Every week, the project received 7.5-8.5 million sterile males of *A. ludens* Tapachula-7 genetic sexing strain, 5-10 million sterile males and females of *A. obliqua*, as well as 5 million of the parasitoid *Diachasmimorpha longicaudata* (Ashmead). With these quantities and based on the experience of the National Campaign, the target release densities were 533 male *A. ludens* / ha, 333 male *A. obliqua* / ha, and 1000 parasitoids / ha. The weekly amounts varied slightly depending on the weekly production of the Moscafrut facility in Metapa, as well as the needs of the National Campaign. For some time during the second year of releases, batches of the bisexual *A. ludens* strain (males and females) were also received, increasing the number of sterile insects released. The opposite was true for *A. obliqua* as the needs of the National Campaign resulted in smaller quantities being received sometimes (see Table 1 and Fig. 4), reducing the release densities.

Table 1. Number of sterile flies received during three release seasons

	2012-13	2013-14	2014-15*
<i>A. ludens</i> Tap-7 males			
Total	499 771 956	436 226 000	269 320 000
Average / week	9 610 999	8 388 961	9 974 815
<i>A. ludens</i> bisexual			
Total	85 729 000	517 932 000	241 365 000
Average / week	1 617 528	9 772 302	7 785 968
<i>A. ludens</i> sum of males			
Total	542 636 456	695 192 000	390 002 500
Average / week	10 419 763	13 275 112	13 867 799
<i>A. obliqua</i>			
Total	470 633 000	505 576 006	244 436 000
Average / week	8 879 868	9 520 302	8 147 867

* In the 2014-15 season, data are included only until week 22 (June 6, 2015)

During the three release seasons, a total of 1205 million sterile *A. ludens* Tap-7 strain (only males), 845 million sterile *A. ludens* bisexual strain (males and females), 1219 million sterile *A. obliqua* (males and females) and 385 million *D. longicaudata* parasitoids were released. The number of sterile flies received in each of the three release seasons, as well as weekly averages, are shown in Table 1.

The quality of these sterile insects is shown in Table 2. From the series of quality control tests that were applied, we selected the percentage of flying flies after chilling as a parameter representing quality of this biological material. In the quality control manual this test is known as "absolute-post-chill flyers" (FAO/IAEA/USDA 2019).

Table 2. Quality of the sterile flies received during three release seasons, as percentage of flying flies after chilling

Strain	2012-13	2013-14	2014-15*
<i>A. ludens</i> Tap-7	81.05	86.14	85.42
<i>A. ludens</i> bisexual	87.47	89.05	85.23
<i>A. obliqua</i>	88.46	89.39	88.26

*For the 2014-15 season, data are included only until week 22 (June 6, 2015)

The mass-production facility in Metapa delivered the biological material to the Mediterranean Fruit Fly Emergence and Release Facility (CEMM by its initials in Spanish), located near the Tapachula airport. All biological material was received as irradiated pupae under hypoxic conditions. The CEMM staff placed the pupae in "Mexico" type emergence towers that were provided with water and food. The food was a mixture of sugar and enzymatic hydrolysed yeast in a 24:1 ratio. The towers were kept in the emergence rooms at 23 ± 1 °C and $65 \pm 5\%$ relative humidity. Adults emerged 2-3 days later and were released once they were sexually mature, i.e. 5 days later in the case of *A. ludens* and 4 days in the case of *A. obliqua*. On the release day, the towers were placed in a cold room at 2-4 °C for one hour to immobilize the adults, and then they were placed in specially designed refrigeration boxes and transported to the airport for chilled aerial release (Hernández et al. 2010). Images of the emergence towers and the release box are shown in Fig. 2.

The services of the Mubarqui® company were contracted to implement the aerial releases of the sterile flies. This company has adapted aircrafts, appropriate release machines, and support infrastructure to implement these releases. For each release flight, a report was generated indicating the time of the flight, the route followed, the number of sterile insects released and the corresponding density. Samples were taken from each batch of sterile insects to assess standardized quality parameters (FAO/IAEA/USDA 2019).

Parasitoids were released from the ground with the support of the staff and vehicles of the State Committee for Plant Health. During the first year of releases, the parasitized pupae were placed in PARC® boxes (Plastic Aerial Release Container) with a mixture of honey and paper as a food source (Fig. 3A).

Figure 2. Towers type "México" used for the emergence of sterile adults (A) and chilled release box being loaded into the aircraft (B).

Figure 3. PARC box (A) and "R2D2" devices (B) used for the emergence and feeding of parasitoids and their subsequent ground release in the field.

After eight days, the emerged parasitoid adults were released. With the aim of improving the performance of these parasitoids, in the following year the release was implemented using “R2D2” devices, which are 20 litres plastic containers with mesh windows on the wall and cover. To increase the surface area, a corrugated plastic honeycomb was placed inside the containers. Each device contained approximately 2000 parasitized pupae (Montoya et al. 2012). The “R2D2” devices are shown in Fig. 3B. These “R2D2” devices replaced the PARC boxes in the second and third release years.

3. RESULTS

3.1. Biological Material

Weekly variations in the number of sterile males released during the three release seasons are shown in Fig. 4.

Figure 4. Number of sterile males released per week in each of the three release seasons. A) *A. ludens* males of the Tapachula-7 and bisexual strains. B) *A. obliqua* males. Season 2012-13 is shown in blue, 2013-14 in orange, and 2014-15 in grey.

For the third season (2014-15), data are shown only up to week 22 when, based on the number and locations of wild fly detections, it was decided to modify the release polygon (see Section 4). It should be noted that since week 10 of this last season, the association of fruit growers took over the funding and coordinating of field activities, fulfilling the goal of technology transfer, and thus transforming a research project into an operational programme.

The number of *A. ludens* sterile males released ranged between 10 and 20 million per week for most of the time for the three release seasons. Numbers for the 2013-14 and 2014-15 seasons were consistently higher. With these quantities, the average densities released were 696, 891 and 849 males per ha for the seasons 2012-13, 2013-14, and 2014-15, respectively. The highest density was 2084 males / ha in week 46 of 2013 and the lowest was 314 males / ha in week 1 of 2013. Considering the natural population dynamics of this species, in the first weeks of the calendar year it is key to have high sterile fly densities in the field, which was achieved in the 2014-15 season.

For *A. obliqua* the quantities of sterile flies were smaller and the variation greater. The average densities released were 302, 323 and 299 males / ha for the seasons 2012-13, 2013-14, and 2014-15, respectively. The highest density was 543 males / ha in week 13 of 2014 and the lowest was 148 males / ha in week 40 of the same year.

As of week 34 of 2014, there was a significant reduction in *A. obliqua* sterile fly availability and from week 49 to 52 of 2014 no biological material was received. This was attributed to production problems at the Moscafrut facility and due to the demand for this species by the National Campaign.

3.2. Sterile Fly Densities

The releases of sterile flies were monitored with Multilure traps deployed inside the area of the release polygon. Out of the total of 109 traps were deployed as part of the three trapping transects, 30 were located inside this polygon. Average fly per trap per day (FTD) values for trapped sterile males in these 30 traps for each season and species are shown in Table 3.

Table 3. Average of sterile males captured per trap per day (FTD) in the release polygon in each of the three release seasons for *A. ludens* and *A. obliqua*

Season	<i>A. ludens</i>	<i>A. obliqua</i>
2012-13	0.766	0.643
2013-14	1.363	0.531
2014-15*	0.472	0.135

*Only until week 22, since the release polygon was modified afterwards

Another parameter used to monitor sterile fly releases was the percentage of traps that trapped sterile flies, regardless of the amount captured. This parameter informs about the uniformity of the releases. Fig. 5 shows how this percentage varied throughout the year for the two species in the three seasons. The average percentage of traps that trapped sterile flies in each season ranged from 53 to 66% for *A. ludens* and 27 to 60% for *A. obliqua*. The lower value in *A. obliqua* corresponded to the 2014-15 season and was related to the suspension of releases from week 49 to 52 due to lack of biological material.

Figure 5. Percentage of traps with capture of sterile flies in each of the three release seasons for *A. ludens* and *A. obliqua*.

The sterile: fertile ratio refers to the number of sterile males compared to the number of fertile or wild males in the monitoring traps. This relationship is the basis of the Knippling model (Knippling 1955), which in turn is the foundation of SIT

application. The ratios achieved for each species and in each season are shown in Table 4. In the case of *A. ludens*, considering the total catches throughout the complete season, the sterile: fertile ratios were always higher than 200:1 and in the 2013-14 season the ratio was 519:1. In *A. obliqua* these ratios were much lower, even in those cases where the number of sterile males trapped was similar to *A. ludens* (i.e. season 2012-13).

Table 4. Number of sterile and fertile or wild males captured in traps and the corresponding sterile: fertile ratio for *A. ludens* and *A. obliqua* in the three seasons

Season	<i>A. ludens</i>			<i>A. obliqua</i>		
	Sterile	Fertile	S:F	Sterile	Fertile	S:F
2012-13	7 936	31	256	6 956	618	11
2013-14	15 058	29	519	5 929	145	41
2014-15*	2 131	10	213	575	25	25

* Only includes the first 22 weeks, since the release polygon was modified afterwards

Empirical evidence indicates that to obtain good suppression, the sterile: fertile ratio must be greater than 30:1, but ideally greater than 100:1 (Flores et al. 2014, 2017). The achieved sterile: fertile ratios were satisfactory in the case of *A. ludens*, particularly in the 2013-14 season, when the average release density was 891 males / ha. While in the case of *A. obliqua*, the lower release densities (averages <350 males / ha) together with the larger wild populations resulted in sterile: fertile ratios much lower than the target of 100:1.

3.3. Wild Population Densities

To make an estimate of wild population levels we used wild female catches. During the four monitoring seasons, considering all the traps, a total of 3792 *A. ludens* and 37 445 *A. obliqua* females were trapped. This represents a 9.8 times greater catch for *A. obliqua*. To assess the effect of the sterile fly releases, only the traps located in the release polygon were considered (Fig. 6).

The wild populations in the first 2012-13 season were higher in the release polygon than in the preceding year without them. In the subsequent 2013-14 and 2014-15 seasons, the density of sterile flies was increased, and this situation was reversed. The populations were significantly suppressed. The suppression effect ranged from 76 - 81% for *A. ludens*, while for *A. obliqua*, despite the low sterile: fertile ratio, suppression ranged from 89 to 91%. The suppression is confirmed by a comparison of the mean numbers of females per trap per two seasons between the release polygon and the traps located at the north of the polygon (Fig. 7), where no control measures were applied, and south of the polygon, where most commercial mango orchards are located and which was the protected area.

Figure 6. Capture of wild females, expressed in FTD (flies per trap per day), for *A. ludens* and *A. obliqua* during four seasons in the release polygon. The 2011-12 season without and the other three seasons with ABC and SIT releases.

Releases of *D. longicaudata* parasitoids resulted in a significant increase in the parasitisation rate. Table 5 shows these rates in the area of the polygon where parasitoids were released and in the control area where no releases were made. Parasitism by *D. longicaudata* in the area where releases were made was 15.12%; the other 1.38% was by native parasitoids. Montoya et al. (2017) provide more detailed information on the effects of the *D. longicaudata* releases.

Table 5. Number of flies, parasitoids and parasitisation rate in the zone with augmentative releases of *D. longicaudata* and the control zone without releases

Zone	Flies	Parasitoids	Parasitism (%)	Fruit samples with parasitoids (%)
Without releases	468	5	1.05	3.8
With releases	5 271	947	16.50	27.7

Figure 7. Mean (SE) capture of wild females expressed in flies per trap for *A. ludens* and *A. obliqua* in the 2012-13 and 2013-14 seasons within the release polygon and in the traps located north and south of the release polygon.

3.4. Infested Batches and the Species of Concern

The differences in abundance observed between the two species - *A. ludens* and *A. obliqua* - were consistent and in agreement with what was previously reported (Aluja et al. 1996). However, this difference did not match the detection of infested batches of mango in the packing houses: more than 94% of the infested lots were by *A. ludens* (information provided by the State Committee for Plant Health of Chiapas) (Table 6).

In 2014, Aluja et al. (2014) reported that mango cultivar Ataulfo was not infested by *A. obliqua* when fruits were still on the trees. Only the fruits known as "mango niño" (baby mango) were infested. These are small fruits of the same cultivar that do not grow as the normal fruits. The Ataulfo cultivar is the one that occupies the largest surface area in Chiapas and represents more than 90% of mango exports. This

observation made us conclude that *A. ludens* was the important species to suppress to minimize or prevent fruit infestation. This new knowledge was fortunate as the programme could receive sufficient sterile male *A. ludens* to achieve densities of 800 to 1000 males per ha, reaching sterile: fertile ratios of more than 100:1.

Table 6. Number of infested batches at the packing houses per species and the percent of those infested by *Anastrepha ludens*

Season	<i>A. obliqua</i>	<i>A. ludens</i>	% <i>A. ludens</i>
2012	21	390	94.9
2013	9	401	97.8
2014	6	236	97.5
2015	3	241	98.8

4. FROM A RESEARCH PROJECT TO AN ACTION PROGRAMME

Considering the four seasons of the research project, we were able to verify and validate the effectiveness of the SIT and the ABC for the suppression of populations of these two species of fruit flies. The strategy of establishing a "biological barrier" between the midlands and highlands with high fruit fly populations, and the lowlands, where the largest area planted with commercial mango is located, seemed to be appropriate to reduce fruit fly infestation in mango from 76% to 91%. Nevertheless, for an action programme, monitoring should be expanded so that the location of this "biological barrier" is dynamic and can be adapted to the situation of the pest. Also, the importance of achieving high sterile to fertile ratios before the start of the mango season should always be kept in mind.

At this stage of the research project, growers were very interested in continuing the releases of sterile insects and parasitoids. They were willing to contribute the needed funds, and to fulfil the requirements to be considered for participation in the National Campaign. It was decided to focus only on *A. ludens*, and the National Campaign offered to provide the programme with 15 million sterile males (Tapachula-7 genetic sexing strain) and 5 million *D. longicaudata* for the ABC.

A technical group to follow up the programme was established with participants from the mango growers' union, the State Plant Health Committee, the National Fruit Fly Campaign and ECOSUR (El Colegio de la Frontera Sur, public research centre). This technical group meets every two weeks or weekly, depending on the time of the year. The technical group agreed on the design of a new release polygon of 15 000 ha based on the pest situation and the availability of biological material. Releases of sterile flies and parasitoids have not been stopped since then. As an example of this follow-up, the situation for week 25 in 2016 is shown in Fig. 8, with the location of the modified release polygon (40 x 3.75 km), the aerial release lines, and the location of the monitoring traps indicating flies captured.

Figure 8. Modified release polygon of the action programme showing flight lines and the location of traps. Colour codes indicate type of trapped flies; sterile - fertile means that both types of flies were captured in the trap; these data correspond to week 25, 2016.

Although there was no immediate suppression effect of sterile flies and parasitoids releases, the continued releases from 2012 to 2017 resulted in a gradual suppression of wild *A. ludens* populations and as a result the number of infested mango batches detected at the packing houses has been greatly reduced. The number of infested batches per season, and the corresponding index of infested batches per ton of exported mangoes are shown in Fig. 9. These results are encouraging and demonstrate the long-term effects of area-wide integration of the SIT and the ABC. They also show that with good knowledge of the dynamics of fruit fly populations it is feasible to design AW-IPM programmes, integrating the SIT and the ABC in the management of fruit flies under tropical conditions where pest populations are normally high.

The challenge now is to maintain and refine the releases of sterile flies and parasitoids and assess whether their synergistic effect will further decrease the pest populations, and in the long term minimize or avoid bait insecticide sprays in the region.

Figure 9. Number of infested batches detected at packing houses per season (A) and index of infested batches per ton of exported mangoes (B). The arrow shows when releases of sterile flies and parasitoids were initiated.

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