

**Release, post-release
evaluation and habitat
management of the
silverleaf whitefly parasitoid**

Dr Paul De Barro
CSIRO Entomology

Project Number: VG06029

VG06029

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Release, post-release
evaluation and habitat
management of the
silverleaf whitefly
parasitoid *Eretmocerus*
hayati

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MEDIA SUMMARY

CSIRO Entomology identified the need to introduce an effective parasitoid of silverleaf whitefly after determining that existing native parasitoids were less effective than required to contribute significantly to management. Releases of *Er. hayati* commenced in late October 2004 and continued through until March 2008. In the space of two years *Er. hayati* has spread from 12 release areas along the east coast of Queensland to now cover much of the current distribution of SLW in eastern Australia. It has also been released and established successfully in Carnarvon, WA and Alice Springs, Katherine and Darwin, NT. There has been a six-fold increase in the average level of parasitism and an overall increase in the frequency of attack such that 76% of all collections now contain parasitised whitefly whereas previously it was 25%. The introduction of *Er. hayati* appears to have had a considerable impact on SLW. Drought which has affected much of Australia during the entire release and post-release period covered by this study may have contributed to the decline in SLW abundance in some areas through the reduction in cropping. However, the decline in SLW numbers in places such as Bundaberg which have so far escaped drought are equivalent to those observed in drought affected areas. In Bundaberg, a recent survey by Growcom has shown that growers have modified crop management practices so as to take advantage of the establishment of *Er. hayati*.

Further investigation on the area-wide management of SLW and its parasitoid *Er. hayati* show that the landscape context can greatly influence SLW and its parasitoid. In agricultural landscapes with intensive production and lots of SLW an area-wide approach is essential, while also suppressing on-farm levels of pests. However, in agricultural landscapes with limited production and few SLW what farmers do on-farm has the greatest impact, but an area-wide approach is beneficial. For *Er. hayati*, an area-wide approach is also essential. Given their high mobility, a refuge providing a source of *Er. hayati* could be established on-farm or at several locations within a region.

Given the successful establishment and spread of *Er. hayati* and understanding of the appropriate spatial scale for managing SLW and *Er. hayati* three questions remain: 1) is the level of parasitism now being achieved sufficient to provide a long-term cost savings in SLW control, and 2) how can we get the most out of *Er. hayati* , and 3) how can we get communities working together on area-wide management?

TECHNICAL SUMMARY

Bemisia tabaci biotype B is a significant pest of agriculture world-wide. Assessments of the potential of parasitoids already present in Australia to control this pest indicated that two species of *Eretmocerus* and 11 species of *Encarsia* were present, but overall contributed an average of $5.0 \pm 0.3\%$ parasitism of 4th instars. Further only 25 % of samples containing biotype B had parasitised individuals present. Overall *Er. mundus* was the most abundant parasitoid prior to the introduction. *Eretmocerus hayati* (VG02016) was identified as the best biocontrol prospect and in Oct 2004 the first releases began. In the space of 3.3 years *Er. hayati* spread from 12 release areas along the east coast of Queensland to now cover much of the current distribution of SLW in eastern Australia as well as northern NSW and isolated infestations in WA and NT. Three years later parasitism now averages $29.3 \pm 0.1\%$ of 4th instars with only 24% of collections having no parasitism present. *Eretmocerus hayati* contributed 85% of the overall apparent parasitism. *Eretmocerus hayati* appears to have had a considerable impact on SLW. Drought which has affected much of Australia during the entire release and post-release period covered by this study may have contributed to the decline in SLW abundance in some areas through the reduction in cropping. However, the decline in SLW numbers in places such as Bundaberg which have so far escaped drought are equivalent to those observed in drought affected areas. The key question is whether the parasitism now being achieved is sufficient to deliver long-term cost savings to growers. To begin to assess this we considered the case for area-wide management of SLW and *Er. hayati*.

The best suppression of pests from biological control agents occur when the agent arrives at the same time or shortly after the pest. Early colonisation of crops by pests and their natural enemies depends on pest and natural enemy populations in the surrounding region. This includes the number and size of the populations and the distance clean and infested crops. To understand the appropriate spatial scale for managing SLW and *Er. hayati*, we investigated: 1) how fast SLW find a newly planted crop, 2) what proportion of the crop they infest and the heaviness of the infestation, and 3) the role of surrounding landscape in new infestations. Investigations were conducted in two different landscapes that were 4km in diameter and 20 km apart. Although the same crops were grown in each landscape, they were in different proportions and one was being farmed much more intensively (45 crops host to SLW totalling 1.7 km²) than the other (16 crops host to SLW totalling 0.6 km²). This affected the numbers of SLW present in the respective landscapes and their distribution across these landscapes. Within each landscape there were two treatments - adjacent to a host crop with SLW and far from a host crop with SLW i.e. more than 250 m away. Sentinel plants were deployed to mimic real fields (around 6 500 in total), either adjacent to a host crop with SLW or greater than 250 m from a host crop. This was repeated three times over a 14 day period.

Our results show that the landscape context can greatly influence SLW and its parasitoid. For SLW, in areas with intense production and lots of SLW the sources of SLW in the landscape (@ scale of 3km) explain the proportion of the crop infested, but sources within 100 m explain whether the infestation is heavy. In areas with limited production and few SLW the density of SLW within 0.5 km explain how much of the crop is infested, and within 100m the size of the infestation. For *Er. hayati*, colonisation was best when there are sources of parasitoids at least within 2.5 kms and new crops are planted next to existing crops. The parasitoids most likely use plant cues to arrest further movement, and to initiate area-restricted searching as they look for hosts to parasitize. The implication of these results is that in agricultural landscapes with intensive production and lots of SLW an area-wide approach is essential, while also suppressing on-farm levels of pests. However, in landscapes with limited production and few SLW what farmers do on-farm has the greatest impact, but an area-wide approach is beneficial. For *Er. hayati*, an area-wide approach is also essential. To control SLW and get the most out of its parasitoid, agricultural communities must work together on developing their pest management plans.

INTRODUCTION

Project V06029 sought to deliver the following outcomes,

- 1) Establishment of *Eretmocerus hayati* leading to a noticeable decline in silverleaf whitefly numbers;
- 2) Understanding of the appropriate scale to achieve effective management of SLW and its parasitoid *Er. hayati*.

To achieve these outcomes the research followed three approaches. The first was to release the parasitoid into vegetable crops in more regions. The second was to monitor for parasitoid establishment, effectiveness, persistence and spread. The third was to develop management strategies for SLW and *Er. hayati* at the appropriate spatial scale, eg. field, farm, and landscape.

Section 1

Post-release evaluation of *Eretmocerus hayati* Zolnerowich and Rose in Australia

Post-release evaluation of *Eretmocerus hayati* Zolnerowich and Rose in Australia

Paul De Barro and Marc Coombs

Introduction

A significant pest of agriculture, the silverleaf whitefly (SLW), *Bemisia tabaci* biotype B (Gennadius, also known as *Bemisia argentifolii*) was first detected in Australia in late 1994 (Gunning *et al.*, 1995); it is likely to have first entered the country some time between mid-1992 and mid-1993. Since its arrival in northern New South Wales, it spread through the wholesale commercial ornamental nursery network to Queensland and Northern Territory and from there to the retail nurseries across Australia. Over the past 13 years it has become an economic problem primarily in Queensland and to a lesser extent in coastal Northern New South Wales, Northern Territory and Carnarvon in Western Australia. Crops most frequently affected include Brassicaceae, Cucurbitaceae, Solanaceae and Fabaceae vegetables, especially melons, cotton and soybean as well as commercial ornamental species. Losses occur as a result of reduced yield and reductions in quality as a consequence of physiological changes in colour, loss of even maturation and contamination with honeydew and sooty mould. At present, begomoviruses have yet to cause any serious concerns.

Goolsby *et al.* (2005) undertook a review of the USDA biological control program in terms of which of the released species had established in the south western USA with a view to identifying potential candidates for introduction into Australia. The USDA program released a total of seven species of *Encarsia* and five species of *Eretmocerus* of which all species of *Eretmocerus* and one species of *Encarsia* established (Goolsby *et al.*, 2005). The study used the climate matching software CLIMEX to produce an index of suitability between the climates of the locations of origin for each of the established *Eretmocerus* species with climates in each of the four areas in the south western USA where releases took place. The resultant index was then used to rank the species. CLIMEX was then used to compare the regions in the USA where the releases took place to Australia. The Lower Rio Grande Valley was identified as having a climate that was most similar to those parts of Australia most affected by the invasion of SLW. Based on the CLIMEX indices and observations on establishment, *Eretmocerus hayati* Zolnerowich and Rose (Hymenoptera: Aphelinidae) was selected as the only candidate species for introduction.

Biological control of whiteflies has had a long history with numerous examples of success (Table 1). While most of the examples involve perennial cropping systems, some success has been achieved against whitefly pests of annual crops. This study considers the case for introduction and the results from the first 3.3 years since releases of *Er. hayati* began and compares them to the period prior to release.

Table 1. Examples of successful biological control introductions against different species of Aleyrodidae.

| Species | Parasitoid | Location | References |
|--|---|---|---|
| <i>Aleurocanthus spiniferus</i> Quaintance | <i>Encarsia smithi</i> (Silvestri) | South Africa | Berg <i>et al.</i> (2000), Berg & Greenland (2001) |
| <i>Aleurocanthus woglumi</i> Ashby | <i>Eretmocerus serius</i> <i>Silvestri</i> , <i>Encarsia opulenta</i> (Silvestri), <i>Amitus hesperidum</i> <i>Silvestri</i> | Cuba; Mexico; Trinidad; South Africa; USA, Florida, Texas | Vail <i>et al.</i> (2001), Berg & Greenland (2001), White <i>et al.</i> (2005) |
| <i>Aleurodicus dispersus</i> Russell | <i>Encarsia dispersa</i> Polaszek | Australia, Queensland; Pacific Island Countries, | Waterhouse & Norris (1989) |
| <i>Aleurodicus dugesii</i> Cockerell | <i>Entedononecremnus krauteri</i> Zolnerowich and Rose, <i>Encarsiella noyesi</i> Hayat | USA, Florida | Nguyen & Hamon |
| <i>Aleurothrixus floccosus</i> Maskell | <i>Cales noacki</i> Howard | USA, California; Sicily; Tunisia | Liotta <i>et al.</i> (2003), Chermiti <i>et al.</i> (1993), Miklasiewicz & Walker (1990) |
| <i>Aleurotrachelus atratus</i> Hempel | <i>Eretmocerus</i> n. sp. | Comoros Island | Borowiec <i>et al.</i> (2007 a) |
| <i>Aleurotuberculatus takahashi</i> David & Subramanian | <i>Eretmocerus longipes</i> Compere | China, Fuzhou | Sengonca & Liu (1998) |
| <i>Bemisia tabaci</i> Gennadius | <i>Eretmocerus hayati</i> Zolnerowich and Rose | USA, Texas | Gould <i>et al.</i> (2008) |
| <i>Dialeurodes citri</i> Ashmead | <i>Encarsia lahorensis</i> (Howard) | Italy, Sicily | Liotta <i>et al.</i> (2003) |
| <i>Parabemisia myricae</i> (Kuwana) | <i>Eretmocerus debachi</i> Rose & Rosen | USA, California; Turkey | Rose & Rosen (1992a,b), Sengonca <i>et al.</i> (1993, 1995, 1998) |
| <i>Siphoninus phillyreae</i> (Haliday) | <i>Encarsia inaron</i> (Walker), <i>Eretmocerus siphonini</i> Viggiani & Battaglia | USA, California; Israel | Jetter KM (2000), Abd- Rabou (2002), Pickett & Wall (2003), Gerling <i>et al.</i> (2004) |
| <i>Tetraleurodes perseae</i> Nakahara | <i>Cales noacki</i> Howard | USA, California | Rose & Woolly (1984a,b) |
| <i>Trialeurodes vaporariorum</i> Westwood | <i>Encarsia formosa</i> Gahan | cosmopolitan | Hoddle <i>et al.</i> (1998) |

Materials and Methods

Host Specificity testing

The process of importation, evaluation and release of *Er. hayati* was undertaken in accordance with the requirements under Australian legislation governing the importation and release of exotic biological control agents.

Culturing of E. hayati. *Eretmocerus hayati* was imported into quarantine at the CSIRO Long Pocket Laboratories, Indooroopilly during September and October 2002 as parasitised mummies of *B. tabaci* (biotype B) from the Lower Rio Grande Valley, Texas, USA. Parasitoids were identified as *Er. hayati* following Zolnerowich & Rose (1997) and comparison of ribosomal ITS1 with material previously obtained and identified at USDA-APHIS Mission, Texas. Cultures of *Er. hayati* were maintained in 3.5 L plastic containers on *Hibiscus rosa-sinensis* L. var Mrs George Davis 'plants' (two 'plants' per container). Each 'plant' consisted of a single stem and leaf rooted in agar in a 45 ml plastic tube. Each plant had previously been infested with *B. tabaci* (biotype B) eggs to achieve a density of 20-30 nymphs/cm². Following egg hatch the first instars were allowed to settle before parasitoids were added to the cage. The first and second instars are the preferred stages for oviposition by *Eretmocerus* parasitising *B. tabaci* (Jones & Greenberg 1998). Parasitism of *B. tabaci* by *Er. hayati* typically averaged 80–98 %.

Pre-release surveys

Surveys to determine the level of apparent parasitism of *B. tabaci* by Hymenoptera already established in Australia were undertaken between 1995 and 1999. The different parasitoids, all members of the genera *Encarsia* and *Eretmocerus* (Hymenoptera: Aphelinidae), found in Australia have been described in De Barro *et al.* (2000a) and Schmidt *et al.* (2001). A total of 2974 collections were made, 1228 from infestations of B and 1746 from AN. At the time of the surveys both B (Mediterranean/Africa/Asia Minor genetic group) and the indigenous Australia genetic group (AN) co-occurred (genetic groups based on Boykin *et al.*, 2007). For each sample RAPD-PCR was used to determine which genetic group the *B. tabaci* belonged to (De Barro & Driver, 1997). Co-infestations of both genetic groups that persist are uncommon as B displaces individuals from the indigenous group (Liu *et al.*, 2007) and any samples where co-infestations occurred were excluded from this study as it is not possible to determine the genetic group of parasitised 4th instars.

The area covered by the surveys is shown in Fig. 1. Leaves infested with 4th instars were collected from *Atriplex rhagodioides*, *Convolvulus arvensis*, *Cucumis melo* (*cantalupensis* & *inodorus*), *Citrullus lanatus*, *Datura* sp., *Emilia sonchifolia*, *Euphorbia cyathophora*, *E. pulcherrima*, *Gossypium hirsutum*, *Helianthus annuus*, *Hibiscus rosa-sinensis*, *Lactuca seriola*, *Lantana camara*, *Lycopersicum esculentum*, *Malva parviflora*, *Malvastrum coromandellum*, *Sida cordifolia* and *Sonchus oleraceus*. Numbers of leaves collected varied and ranged from 20 to 100 and were based on the numbers of whitefly infested leaves collected from plants at a given location in 15 minutes. The leaves were collected from the part of the plant where a preliminary assessment identified the presence of 4th instars. Throughout the study only the 4th instar was assessed for parasitism as visual detection of parasitism in younger instars is unreliable and these individuals seldom survive on the collected leaves sufficiently long to enable the parasitoid to complete development. Nymphs were counted within 2.2 cm diameter (3.8 cm²) leaf discs. In the 4th instar the shape of the parasitoid larva can be clearly seen through the integument as can the presence of meconium pellets in *Encarsia*; nymphs were determined as being parasitised or unparasitised with the aid of a stereo

dissecting microscope. If parasitised, the parasitoid larvae were identified to genus on the basis of its shape and the presence of meconium. The leaves were then placed in emergence chambers until all the parasitoids had emerged. Parasitoids were identified to species using the descriptions in De Barro *et al.* (2000a) and Schmidt *et al.* (2001). Mean parasitism per collection was calculated by dividing the number of 4th instars present by the number that was parasitised.

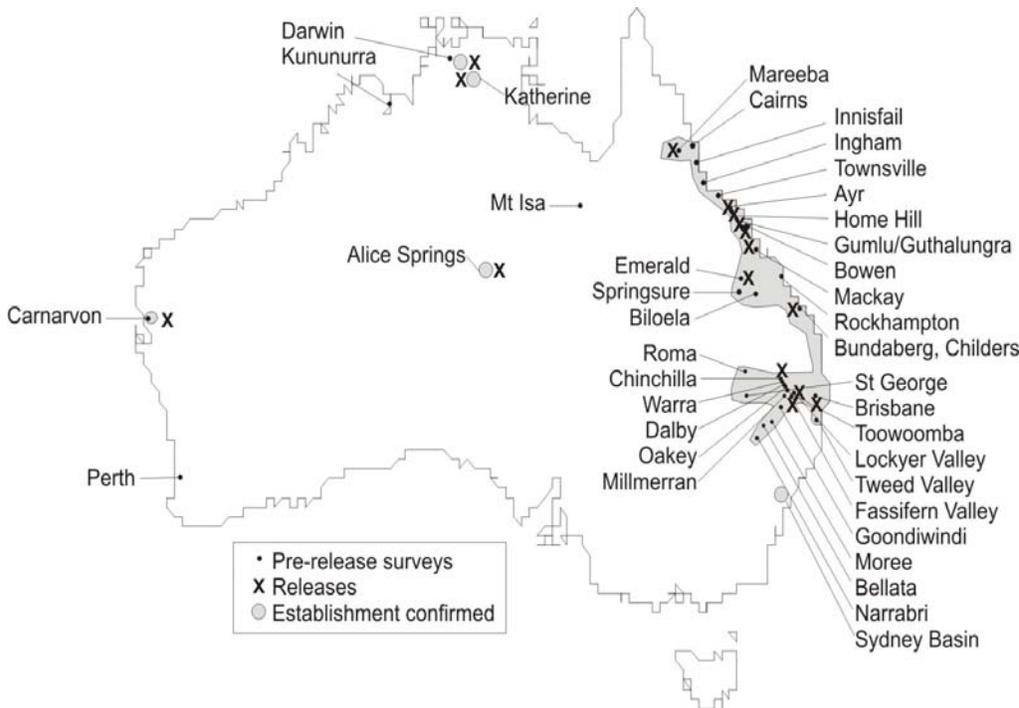


Fig. 1. Map showing location of pre-release surveys, release sites and the area where establishment has been confirmed through post-release surveys.

Post-release surveys

A total of approximately 637,000 *Er. hayati* were released between October 2004 and March 2005 in the Bundaberg-Childers, Lockyer Valley and Emerald production areas, 390,000 between July 2005 and April 2007 in Alice Springs, Ayr, Bowen, Darwin, Gumlu, Guthalungra, Home Hill, Katherine and Mareeba and 40,000 on 30 March 2008 in Carnarvon (Fig. 1, Table 2). By the time the releases of *Er. hayati* commenced, the indigenous genetic group of *B. tabaci* (biotype AN) had been displaced from across much of the range of the invader (Liu *et al.* 2007) and all *B. tabaci* collected were assumed to belong to B. A total of 712 collections were made between November 2004 and March 2008. Collections were made primarily from commercial crops of *Phaseolus vulgaris*, *Brassica oleracea* (broccoli, cabbage, cauliflower), *Gossypium hirsutum*, *Cucumis sativus*, *Solanum melongena*, *Dolichos lablab*, *Solanum tuberosum*, *Ipomea batatas*, *Lycopersicon esculentum*, *Cucumis melo* (*cantalupensis* & *inodorus*), *Citrullus lanatus*, *Cucurbita maxima*, *Cucurbita moschata*, *Glycine max*, the ornamentals *Duranta repens*, *E. pulcherrima*, *Gerbera* sp. and *Hibiscus rosa-sinensis* and the weeds *Sonchus oleraceus*, *Emilia sonchifolia* and *Lantana camara*. Leaves were collected and assessed as in the pre-release surveys.

Bundaberg 1997-2006

The survey data for the Bundaberg production area spans the period prior to the first outbreaks of *B. tabaci* (biotype B) through to the post-release evaluation period. It provides a good opportunity to compare the changes in whitefly density. A total of 372 collections were made prior to the release of *Er. hayati* and 151 post-release. Collections consisted of 20 – 100 leaves and followed the protocol outlined above.

Statistical analysis

The results are presented as means \pm standard error and all percentage data were arcsine transformed before analysis. Pre-release data were analysed using two sample t-tests as were the host specificity testing data. The data for the Bundaberg 1997-2006 surveys were analysed using ANOVA and significant differences between means identified using LSD.

Results

Pre-release surveys 1995-1999

Across all collections made during this period $9.1 \pm 0.3\%$ of 4th instars were observed to be parasitised. Further, 76% of those collections taken from B and 58% from AN infestations had no parasitism (Figs 2). When nymphs were partitioned in regards to their genetic group there was a 2.4 fold difference in parasitism between B ($5.0 \pm 0.3\%$) and AN ($12.0 \pm 0.2\%$) (Fig. 2, arcsine transformed, t-test, $t=12.2$, $P<0.001$). *Eretmocerus* contributed to 91.5% of the overall observed parasitism, to 83.9% of the parasitism of B and 93.7% of AN. Parasitism by *Encarsia* was a very minor component of the overall parasitism (Fig. 2). In total eight species contributed 8.5% of the total parasitism, 16.1% for B and 6.3% for AN. *Eretmocerus mundus* was by far the most abundant species observed (Fig. 2) accounting for 87.7% of the total apparent parasitism, 67.3% for B and 93.7% for AN. *Eretmocerus queenslandensis* contributed 3.8% of the total parasitism and 16.6% for B, but no parasitism of AN was observed. Mean parasitism by *Er. mundus* on B was $3.4 \pm 0.3\%$ and $11.2 \pm 0.2\%$ on AN. Further, *Er. mundus* was represented in 18.1% of the collections.

There was a significant difference in the densities of B and AN with B biotype densities averaging 4.9 ± 0.1 4th instars/cm² and AN 3.4 ± 0.1 4th instars/cm² and no AN densities exceeded 15 4th instars/cm² (t-test, $t=11.0$, $P<0.001$) where as the maximum B densities ranged between 30 and 40 4th instars/cm². The relationship between the percentage parasitism by *Er. mundus* and whitefly density for both B and AN is negatively correlated suggesting a density dependent relationship (Fig. 3).

Post-release surveys 2004-2007

There was no relationship between establishment and the number of individuals released as all releases resulted in establishment (Table 2). The post release surveys showed that *Er. hayati* had spread well beyond the immediate release areas (Fig. 1). Mean parasitism across all collections was $29.3 \pm 0.1\%$ of 4th instars and 76% of collections had parasitism (Figs 2). Of these *Er. hayati* contributed to $23.6 \pm 1.0\%$ of the apparent parasitism or 85.0% of the overall parasitism. Of the collections made, *Er. hayati* was present in 71.2% while *Er. mundus* was in 9.8%. Mean parasitism by *Er. mundus* was $1.2 \pm 0.2\%$ and contributed to 5.2% of the apparent parasitism. None of the

remaining species contributed to more than 2% of the 4th instars parasitised (Figs 2); of them *E. lutea* (Masi) 6.4% and *E. formosa* 3.7% were the next most commonly observed species. During the sampling period the average whitefly density was $1.2\% \pm 0.2$ 4th instars/cm² and there was no density dependent relationship between whitefly density and parasitism by *Er. hayati* (Fig. 3) however the nymph densities were only a quarter of those observed for B in the pre-release surveys with only 3 collections exceeding 20 4th instars/cm².

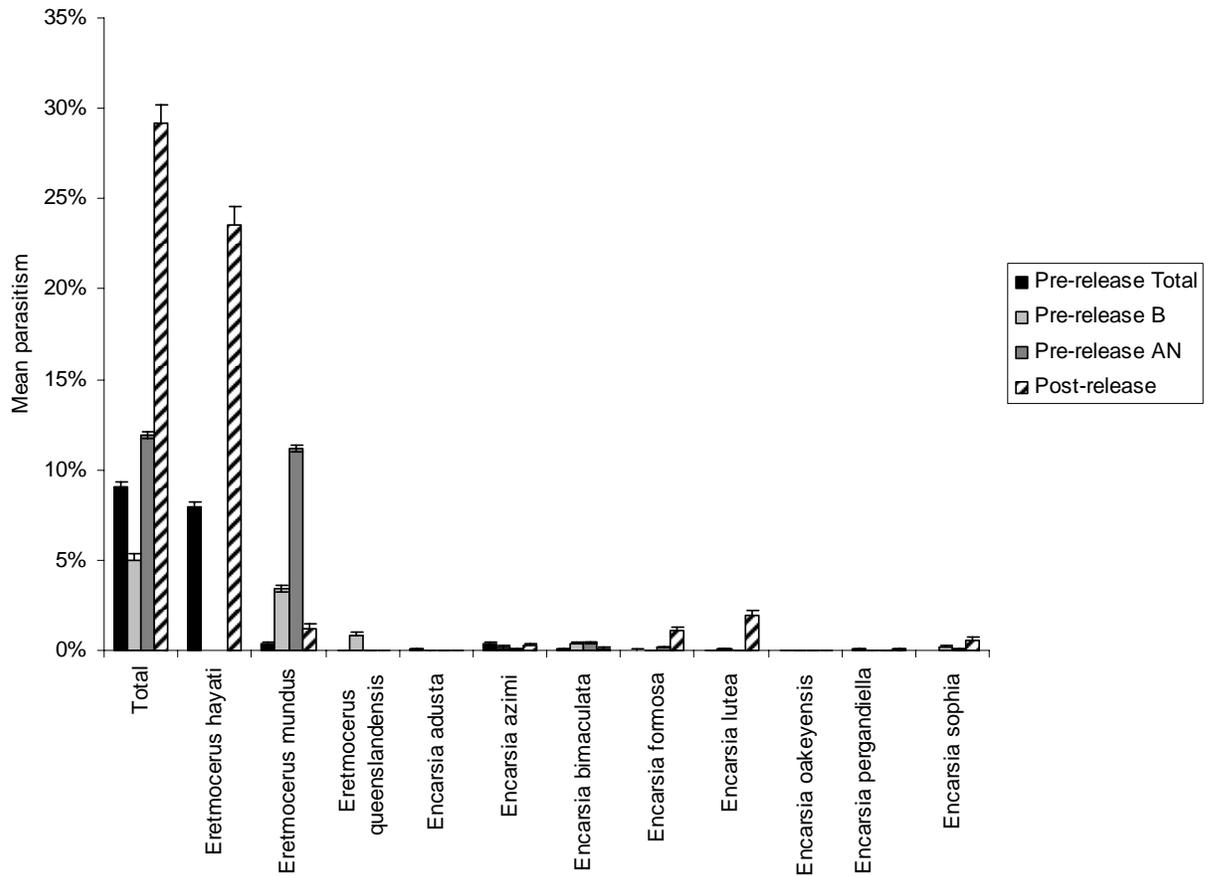


Fig. 2. Percent parasitism for each of the collections made during the pre-release (1995-1999) and post-release (2004-2008) surveys ranked from highest to lowest % parasitism. In the pre-release surveys there were 937 collections in which no parasitism was observed and 173 in the post-release surveys.

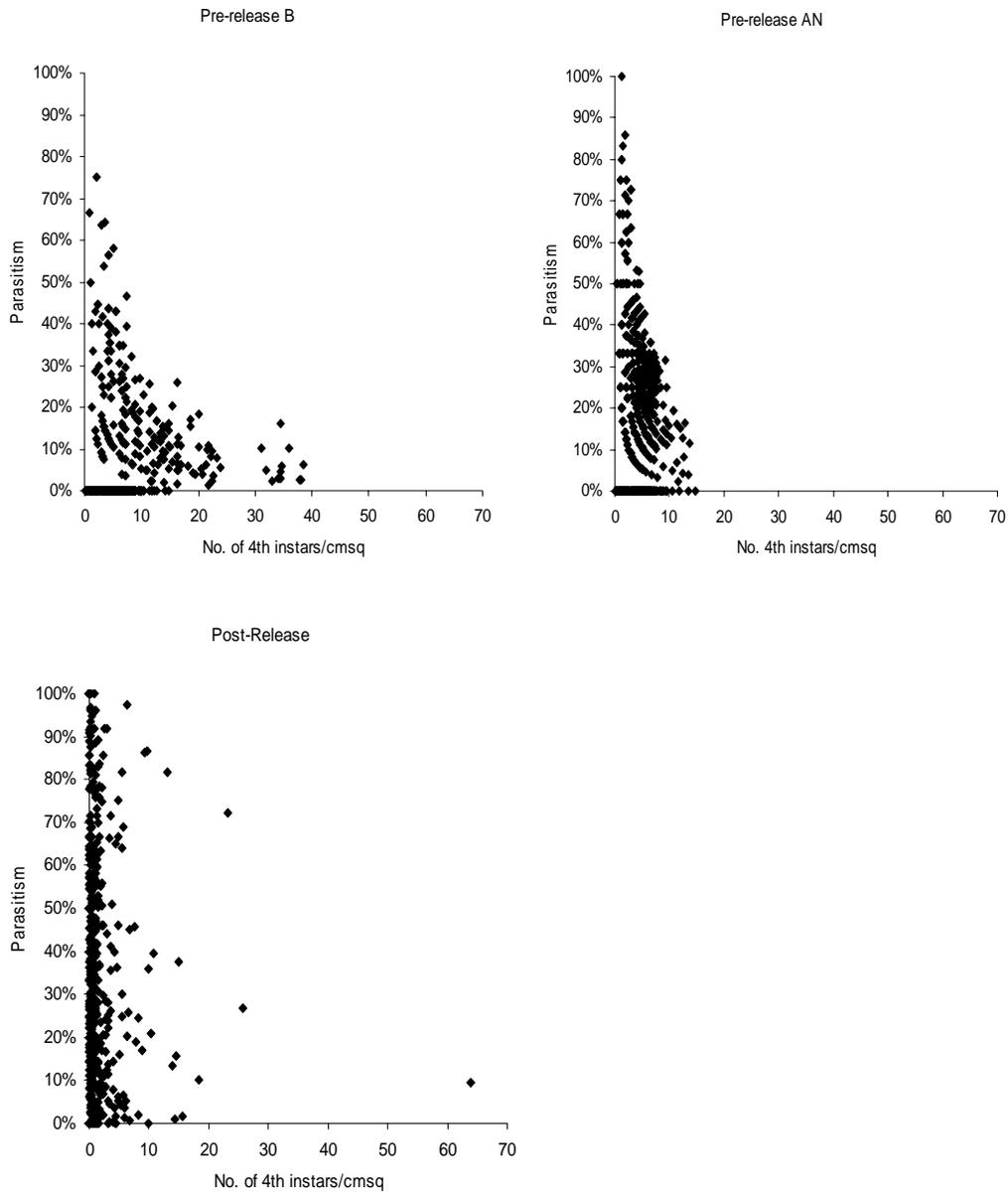


Fig. 3. The relationship between percentage parasitism by *Er. mundus* and B and AN *B. tabaci* densities and the relationship between percentage parasitism by *Er. hayati* and the B biotype.

Table 2. A total of 1,067,000 *Er. hayati* were released between 29 Oct 2004 and 30 Mar 2008. The numbers of releases at any location ranged from 1500 to 130,000 individuals.

| Date | Locality | Lat Long | Crop type | No. released (1,000s) |
|--------------|---------------|------------------------------|----------------|-----------------------|
| 29 Oct 2004 | Lowood | 27° 26' 38 S; 152° 36' 25 E | soybean | 5 |
| 29 Oct 2004 | Gatton | 27° 32' 55 S; 152° 17' 39 E | pumpkin | 14 |
| 5 Nov 2004 | Bundaberg | 24° 51' 6 S; 152° 26' 12 E | melon/zucchini | 30 |
| 9 Nov 2004 | Gatton | 27° 34' 8 S; 152° 16' 17 E | eggplant | 5 |
| 10 Nov 2004 | Gatton | 27° 29' 16 S; 152° 26' 2 E | pumpkin | 10 |
| 17 Nov 2004 | Childers | 25° 3' 55 S; 152° 15' 9 E | tomato | 5 |
| 17 Nov 2004 | Bundaberg | 24° 51' 6 S; 152° 26' 12 E | melon | 5 |
| 17 Nov 2004 | Bundaberg | 24° 47' 3 S; 152° 13' 9 E | eggplant | 5 |
| 24 Nov 2004 | Gatton | 27° 39' 21 S; 152° 22' 44E | soybean | 2 |
| 24 Nov 2004 | Gatton | 27° 40' 4 S; 152° 22' 14 E | pumpkin | 2 |
| 25 Nov 2004 | Helidon | 27° 34' 32 S; 152° 09' 13 E | tomato | 5 |
| 28 Nov 2004 | Childers | 25° 3' 55 S; 152° 15' 9 E | tomato | 2.5 |
| 28 Nov 2004 | Bundaberg | 24° 51' 6 S; 152° 26' 12 E | melon | 7 |
| 3 Dec 2004 | Helidon | 27° 33' 30 S; 152° 7' 46 E | tomato | 10 |
| 3 Dec 2004 | Grantham | 27° 34' 13 S; 152° 10' 38 E | pumpkin | 1.5 |
| 14 Dec 2004 | Bundaberg | 24° 51' 06 S; 152° 26' 12 E | melon | 10 |
| 14 Dec 2004 | Childers | 25° 3' 55 S; 152° 15' 9 E | melon | 5 |
| 21 Dec 2004 | Helidon | 27° 33' 24 S; 152° 8' 7 E | tomato | 40 |
| 23 Dec 2004 | Logan Village | 27° 46' 0 S; 153° 5' 60 E | herbs | 50 |
| 2 Feb 2005 | UQ Gatton | 27° 32' 31 S ; 152° 21' 35 E | soybean | 60 |
| 4 Feb 2005 | UQ Gatton | 27° 32' 31 S ; 152° 21' 35 E | soybean | 50 |
| 8 Feb 2005 | UQ Gatton | 27° 32' 31 S ; 152° 21' 35 E | soybean | 60 |
| 9 Feb 2005 | Bundaberg | 24° 51' 23 S; 152° 25' 6 E | soybean | 10 |
| 13 Feb 2005 | Gatton | 27° 36' 40 S; 152° 16' 34 E | soybean | 50 |
| 21 Feb 2005 | Gatton | 27° 39' 34 S; 152° 22' 40 E | broccoli | 3 |
| 10 Mar 2005 | Aratula | 27° 56' 45 S; 152° 34' 57 E | green bean | 130 |
| 17 Mar 2005 | Forest Hill | 27° 35' 20 S; 152° 22' 30 E | green bean | 20 |
| 17 Mar 2005 | Emerald | 24° 7' 10 S; 148° 5' 26 E | sunflower | 20 |
| 17 Mar 2005 | Emerald | 23° 32' 27 S; 148° 9' 18 E | cotton | 20 |
| 22 Oct 2005 | Ayr | 19° 36' 10 S; 147° 24' 27 E | melon | 25 |
| 22 Oct 2005 | Ayr | 19° 46' 13 S; 147° 13' 2 E | sow thistle | 25 |
| 22 Oct 2005 | Gumlu | 19° 53' 11 S; 147° 41' 39 E | eggplant | 20 |
| 22 Oct 2005 | Guthalungra | 19° 55' 49 S; 147° 50' 12 E | melon | 20 |
| 22 Oct 2005 | Gumlu | 19° 52' 28 S; 147° 43' 08 E | eggplant | 20 |
| 23 Oct 2005 | Home Hill | 19° 41' 14 S; 147° 26' 20 E | melon | 25 |
| 23 Oct 2005 | Home Hill | 19° 40' 13 S; 147° 27' 10 E | melon | 25 |
| 23 Oct 2005 | Bowen | 19° 59' 15 S; 148° 12' 59 E | tomato | 20 |
| 23 Oct 2005 | Bowen | 19° 58' 38 S; 148° 11' 53 E | tomato | 20 |
| 23 Oct 2005 | Bowen | 19° 59' 26 S; 148° 11' 32 E | tomato | 20 |
| 23 Oct 2005 | Bowen | 19° 59' 21 S; 148° 12' 38 E | tomato | 20 |
| 31 Oct 2005 | Mareeba | 16° 59' 18 S; 145° 31' 27 E | tomato | 25 |
| 10 Mar 2007 | Bowen | 19° 59' 20 S; 148° 12' 28 E | bean | 10 |
| 9 Mar 2007 | Ayr | 19° 35' 11 S; 147° 24' 18 E | weeds | 15 |
| 9 Mar 2007 | Home Hill | 19° 40' 42 S; 147° 24' 19 E | weeds | 15 |
| 2/3 Apr 2007 | Mareeba | 17° 2' 18 S; 145° 25' 27 E | tomato | 40 |
| 29 Apr 2007 | Katherine | 14° 32' 02 S; 132° 27' 29 E | melons | 15 |
| 29 Apr 2007 | Darwin | 12° 34' 37 S; 131° 15' 14 E | melons | 15 |
| 29 Apr 2007 | Alice Springs | 23° 44' 12 S; 133° 51' 24 E | melons | 15 |

Bundaberg 1997-2006

The marked order of magnitude increase in whitefly densities between 1997 and 1998 marks the start of outbreaks in the Bundaberg production area (Fig. 4). On 5 November 2004 a total of 30,000 *Er. hayati* were released in Bundaberg and by 14 December 2004 a further 27,000 had been released. Prior to the release, levels of parasitism were consistently less than 5% over the period 1997 to 2000 and again in 2004 just prior to the first release (Fig. 5). During the post-release monitoring period January 2005-December 2006 152 samples were collected. Over the 24 months following the releases whitefly densities declined significantly to levels equivalent to that seen in 1997 (Fig. 4) (ANOVA, $F_{12,1702}=256.3$, $P<0.001$, $LSD=4.7$). Further, parasitism increased significantly from a maximum average of $2.8\pm 0.3\%$ prior to the first release to a minimum of $33.1\pm 4.2\%$ and an average over the period of $43.7\pm 2.3\%$ (Fig. 4) (arcsine transformed, ANOVA, $F_{12,1702}=107.5$, $LSD=18.2$). *Eretmocerus hayati* accounted for 89.9% of the parasitism observed, *Er. mundus* 3.9%, *E. lutea* 2.9%, *E. formosa* 1.5% with *E. azimi*, *E. bimaculata*, *E. pergandiella* and *E. sophia* contributing 1.8% between them. In addition, only 4.6% of collections recorded no parasitism whereas between 1997 and 2004 89.2% of the 461 samples from B infestations collected had no parasitism.

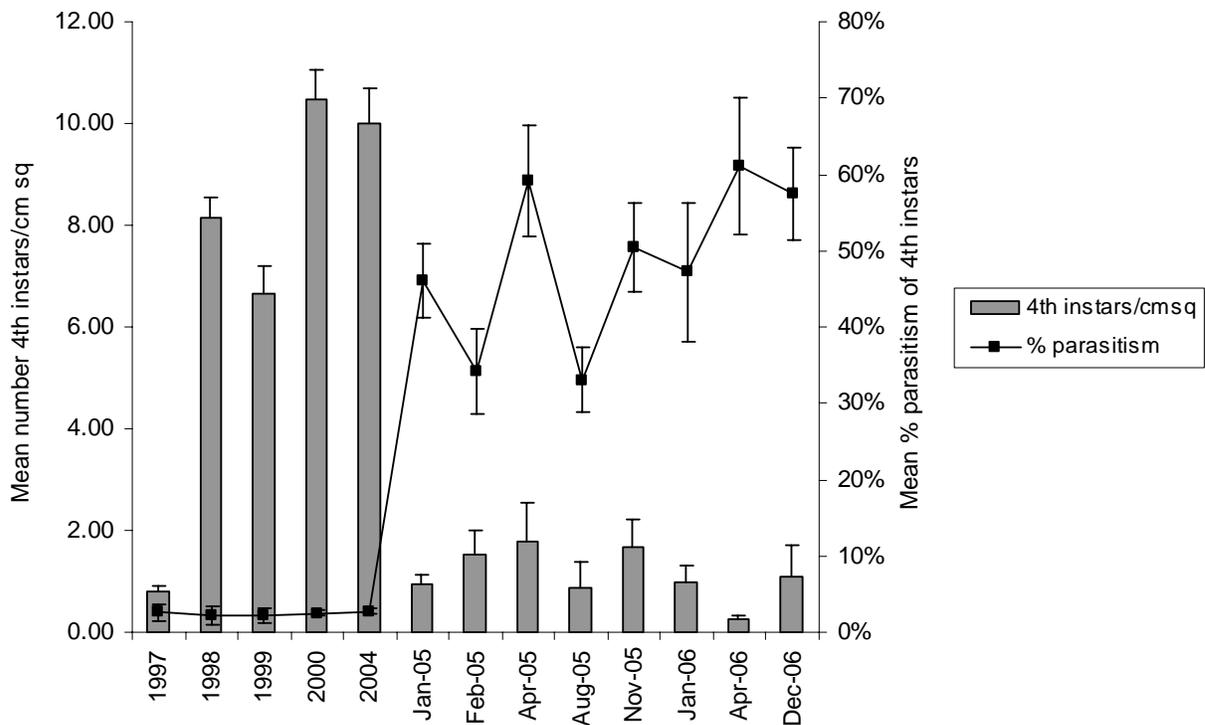


Fig. 4. The mean number of 4th instar *B. tabaci* between 1997 and 2006 together with the mean percentage parasitism over the same period. A total of 57,000 *Er. hayati* were released in Bundaberg between 5 November and 14 December 2004.

Host plants and parasitism

In pre-release surveys eight host plant species represented >98% of the collections made (Table 3). Counts of the number of collections with and without nymphs parasitised by *Er. mundus* indicated that *E. sonchifolia*, *Eu. cyathophora*, *L. camara* and *S. oleraceus* all had lower than expected levels of parasitism of B (Table 3 for significance values). When the numbers of collections of B for each of these hosts was compared against the same hosts in the post-release surveys, *E. sonchifolia*, *Eu. cyathophora* and *S. oleraceus* all showed an increase in numbers of collections containing *Er. hayati* parasitised B while *L. camara* showed no change (Table 3 for significance levels). Further, the collection count for *G. hirsutum* also increased relative to the pre-release counts while remaining unchanged for *H. annuus* (Table 3). The mean percentage overall parasitism by all sources combined showed significantly more parasitised AN with the exception of *Malvastrum coromandellum* (Table 3). Counts for the numbers of collections with and without *B. tabaci* parasitised by *Er. hayati* for a further 10 species of host plant which together with the previous five species made up 87.2% of the post-release collections are also provided in Table 3. All showed more collections with parasitism than without, the exception being *D. repens*. There was a significant increase in mean parasitism for all host plant species common to both pre and post-release surveys (Table 3).

Table 3. The pre-release association between host plant and the numbers of collections with parasitism of either B or AN *B. tabaci* by *Er. mundus* and the mean % parasitism from all sources using the eight most commonly collected host plants which represent 98.2% of collections made during the surveys. The association between counts was analysed using Pearson's Chi Square except for * where samples sized required Fisher's exact test to be used; means were compared using the t test. Also, the post-release comparison between host plant and the numbers of collections containing parasitism of B by *Er. hayati* and mean % parasitism from all sources in the post-release surveys using the 15 most commonly collected host plants which represent 87.2% of collections. Data associated with host plants common to both surveys denoted by ¹.

| Host plant | AN parasitised | AN unparasitised | B parasitised | B unparasitised | P | AN % total parasitism | B % total parasitism | P | |
|---|----------------|------------------|---------------|-----------------|--------------------------|-----------------------|----------------------|---------|--|
| Pre-release counts (<i>Er. mundus</i>) | | | | | Mean % parasitism ± s.e. | | | | |
| <i>Emilia sonchifolia</i> ¹ | 35 | 50 | 4 | 46 | P<0.001 | 11.9±2.1 | 3.5±1.9 | P<0.001 | |
| <i>Euphorbia cyathophora</i> ¹ | 0 | 67 | 0 | 5 | | 7.5±1.3 | | | |
| <i>Gossypium hirsutum</i> ¹ | 52 | 220 | 30 | 125 | P>0.05 | 8.3±1.1 | 3.3±0.8 | P<0.01 | |
| <i>Helianthus annuus</i> ¹ | 35 | 46 | 13 | 33 | P>0.05 | 12.8±1.9 | 5.4±1.5 | P<0.01 | |
| <i>Lactuca seriole</i> * | 5 | 7 | 2 | 5 | P>0.05 | 12.5±6.0 | 5.7±3.9 | P<0.01 | |
| <i>Lantana camara</i> ¹ | 14 | 11 | 1 | 10 | P<0.01 | 14.6±3.0 | 2.0±2.0 | P<0.001 | |
| <i>Malvastrum coromandellum</i> * | 5 | 5 | 3 | 2 | P>0.05 | 15.9±6.0 | 9.0±5.4 | P>0.05 | |
| <i>Sonchus oleraceus</i> ¹ | 555 | 621 | 167 | 747 | P<0.001 | 12.9±0.5 | 5.0±0.4 | P<0.001 | |
| Post-release counts (<i>Er. hayati</i>) | | | | | | | | | |
| <i>Brassica oleracea</i> | | | 11 | 9 | | | 9.0±4.8 | | |
| <i>Citrullus lanatus</i> | | | 14 | 5 | | | 45.9±7.6 | | |
| <i>Cucumis melo</i> | | | 22 | 6 | | | 47.7±6.7 | | |
| <i>Cucurbita maxima</i> | | | 16 | 13 | | | 17.7±5.0 | | |
| <i>Dolichos lablab</i> | | | 11 | 0 | | | 37.9±11.4 | | |
| <i>Duranta repens</i> | | | 4 | 18 | | | 0.5±0.5 | | |
| <i>Emilia sonchifolia</i> ¹ | | | 18 | 6 | P<0.001 | | 39.3±6.2 | P<0.001 | |
| <i>Euphorbia cyathophora</i> ¹ | | | 24 | 1 | P<0.001 | | 30.7±4.9 | P<0.001 | |
| <i>Euphorbia pulcherrima</i> | | | 18 | 1 | | | 9.0±3.0 | | |
| <i>Glycine max</i> | | | 39 | 3 | | | 40.8±4.2 | | |

| | | | | | |
|--|-----|----|---------|-----------|---------|
| <i>Gossypium hirsutum</i> ¹ | 85 | 20 | P<0.001 | 33.9±2.9 | P<0.001 |
| <i>Helianthus annuus</i> ¹ | 9 | 10 | P>0.05 | 51.3±10.4 | P<0.001 |
| <i>Ipomea batatas</i> | 27 | 5 | | 39.1±5.4 | |
| <i>Lantana camara</i> ^{1*} | 4 | 10 | P>0.05 | 9.9±4.0 | P<0.001 |
| <i>Lycopersicum esculentum</i> | 24 | 10 | | 21.1±3.4 | |
| <i>Sonchus oleraceus</i> ¹ | 140 | 38 | P<0.05 | 30.9±2.0 | P<0.001 |

Discussion

A comparison of our pre-release survey data with those from Naranjo (2007) supported the conclusion that the pre-release guild of parasitoids in Australia was unlikely to provide the levels of parasitism required to provide useful reductions in whitefly numbers. Further, results from the Lower Rio Grande, Texas, USA (Goolsby *et al.*, 2005; Gould *et al.*, 2008) indicated that the introduction of *Er. hayati* would contribute to meaningful reductions in SLW abundance by substantially increasing the overall level of parasitism. The no choice tests demonstrated that *Er. hayati* had an extremely narrow host range and the level of non-target attack was considered too low to pose a threat to *L. atriplex* and permission to release was granted in September 2004.

In the space of 3.3 years *Er. hayati* has spread from 12 release areas along the east coast of Queensland to now cover much of the current distribution of SLW in eastern Australia. There has been a six-fold increase in the average level of parasitism and an overall increase in the frequency of attack such that 76% of all collections now contain parasitised whitefly whereas previously it was 25%. This suggests that *Er. hayati* has a superior host finding capacity when compared with other parasitoids present in Australia. Further, whitefly host plants with either no or reduced levels of parasitism of B prior to the releases, showed considerable increases in parasitism and overall SLW densities have declined by 75% since the releases began. The rapid rate of spread may in part be due to the apparent intrinsic capacity of the parasitoid to disperse widely (N. Schellhorn & P. De Barro unpublished data), but it is also due to the parasitoid being able to readily parasitise whiteflies infesting commercial ornamental nurseries (P. De Barro data collected as part of this study). There is certain circularity here, as the same industry which so effectively spread SLW across Australia upon its introduction would now appear to be responsible for spreading its natural enemy.

The majority of parasitism in the pre- and post-release surveys was due to *Er. mundus* in the former and *Er. hayati* in the latter. Levels of parasitism by *Encarsia* spp. were only ever a minor contribution and so will not be discussed further. The pre-release surveys showed a marked difference in the levels of parasitism of B and AN with *Er. mundus* parasitising of a third fewer B. It is important at this point to note that while *Er. mundus* from Australia are morphologically identical to *Er. mundus* elsewhere in the world, they are genetically distinct (De Barro *et al.*, 2000a) from those in Europe and the USA. Further, *Er. mundus* has two modes of reproduction, arrhenotoky, where males are produced and thelytoky where only females are produced. Elsewhere in the world, the arrhenokous population is the more common although there are records of both occurring together in Egypt (Abd-Rabou & Ghahari, 2005), Iran (Ghahari *et al.*, 2005) and the USA (Powell & Bellows, 1992). In Australia the population appears to be entirely thelytokous (De Barro & Hart, 2001; Ardeh *et al.*, 2005 a,b).

There are several possible explanations for the lower level of parasitism in B. Firstly, as indicated earlier, AN and B belong to different genetic groups and a comparison of mitochondrial CO1 sequences indicates an average divergence of 18% (based on the comparison of sequences used in Boykin *et al.*, 2007). Increasingly, using CO1, species level divergence is associated with levels of divergence $\leq 3\%$ (Hebert *et al.* 2003). The level of divergence suggests that AN has been in Australia for a considerable period of time and so it is likely that the Australian *Er. mundus* has had considerable opportunity to co-evolve with AN and may have become physiologically and behaviourally better adapted to AN than B. One difference between B and AN shown by this study is that B forms denser infestations than AN and so it is possible that the Australian *Er. mundus* may simply be unable to adapt to the higher population densities

of B. De Barro *et al.* (2000b) also assessed the capacity of *Er. mundus* to parasitise different densities of B on tomato and rockmelon. They showed no negative effect of density, but as densities were below 6 nymphs/cm² it is not possible to predict the response to the higher densities that were often encountered in our surveys. Further research is therefore needed to resolve the role of host density in the performance of the two parasitoids.

Analysis of the post-release survey data showed no evidence for a density dependent relationship between *Er. hayati* and *B. tabaci*. This is unusual as one would normally expect to find such a relationship. The most likely explanation would be that the population, having only recently been introduced, is still in a state of disequilibrium which is contributing to the lack of evidence for such a relationship.

While physiological differences between AN and B may be contributing to the lower than expected levels of parasitism of B, it is more probable that host plant is exerting an effect on the parasitoid, either directly or via the nymph and this is leading to the reduced parasitism. Three of the most frequently collected hosts, *E. sonchifolia*, *L. camara* and *S. oleraceus* in the pre-release surveys all showed significantly reduced parasitism of B relative to AN. Of these three hosts, *S. oleraceus* made up 74% of the collections with only 18% having parasitised nymphs present, an observation which tends to support the role for a tritrophic interaction leading to reduced parasitism. Such tritrophic interactions are not unexpected in host-parasitoid interactions. Leaf hairs and leaf waxiness have previously been shown to significantly affect parasitism of whiteflies by aphelinids. McAuslane *et al.* (2000) observed reductions in leaf wax in collards were associated with increased levels of parasitism of B by both *Eretmocerus* sp. and *E. pergandiella*. Qui *et al.* (2005) demonstrated that performance of *Er.* sp. nr *furuhashii* declined as leaf hair density increased. Leaf hairs interfering with movement and host finding and resulting in reduced levels of parasitism have also been shown for *E. formosa*, *Er. eremicus* and *Er. rui* (Li *et al.*, 1987; Headrick *et al.*, 1996a, b; McAuslane & Nguyen, 1996). However, *E. sonchifolia* and *S. oleraceus* are both glabrous and *L. camara* is weakly pubescent (<http://plantnet.rbgsvd.nsw.gov.au/floraonline.htm>). Furthermore, a fourth host from this study, *Eu. cyathophora*, which is also glabrous, showed no parasitism for *Er. mundus* and attempts to establish this parasitoid on both AN and B in the laboratory failed (P. De Barro, unpublished data). This suggests that while leaf hairs are responsible for reduced performance in other studies, they do not provide an adequate explanation for our results. In contrast, *Er. hayati* showed no such inability and readily parasitised B on *E. sonchifolia*, *Eu. cyathophora* and *S. oleraceus*. Further, it markedly increased the frequency of parasitism of B on *G. hirsutum*. In the post-release surveys only two hosts, *L. camara* and *D. repens* showed more collections without parasitism than with. It would therefore appear that part of the success of *Er. hayati* is its ability to attack B on host plants that *Er. mundus* was less able to utilize.

Plant community structure can have a significant influence on herbivore and parasitoid population dynamics. Goolsby *et al.* (1996, 1998) have shown that parasitism by *Er. hayati* varies considerably across different host plant species. Plant characteristics, such as shape, colour and structure, and other plant cues affect the capacity for parasitoids to search plant communities for infested plants and influence the time taken to find prey (Waage, 1979; Gingras *et al.*, 2002; Vos & Hemerik, 2003; Wang & Keller, 2004; Tentelier *et al.*, 2005). Factors such as these also influence the distribution of parasitoid attacks and can lead to the creation of enemy-free space for hosts on less attractive plants (Bukovinszky *et al.*, 2007). In this case rather than changing the structure of plant communities, one explanation is that the introduction of a parasitoid that has different searching abilities has greatly reduced the available enemy free space thereby exposing a greater portion of the population to attack.

In terms of non-target attack on whiteflies, current surveys have only detected field parasitism in *B. tabaci*. Whether *Er. hayati* has had any impact on the indigenous AN *B. tabaci* is difficult in part because the widespread presence of the invasive SLW has led to the displacement of the indigenous population (Liu *et al.*, 2007).

The introduction of *Er. hayati* appears to have had a considerable impact on SLW. Drought which has affected much of Australia during the entire release and post-release period covered by this study may have contributed to the decline in SLW abundance in some areas through the reduction in cropping. However, the decline in SLW numbers in places such as Bundaberg which have so far escaped drought are equivalent to those observed in drought affected areas. In Bundaberg, a recent survey by Growcom (<http://www.growcom.com.au/home/default.asp>) has shown that growers have modified crop management practices so as to take advantage of the establishment of *Er. hayati*.

Given the successful establishment and spread of *Er. hayati*, the key question is whether the levels of parasitism now being achieved are sufficient to make an economic difference in regards to suppression of SLW populations. Naranjo & Ellsworth (2005) and Naranjo (2007) considered the Arizona cotton system prior to the establishment of several introduced species) and Horowitz *et al.* (1984) concluded that in Maricopa, Arizona and Israel, parasitoids contributed very little irreplaceable mortality. In the case of Arizona cotton, irreplaceable mortality contributed by parasitism was 1% with a further 5% of irreplaceable mortality from all sources combined being required to achieve economic suppression while a long term key factor analysis of life table studies in the Arizona cotton system between 1997 and 2007 showed no appreciable increase in mortality due to parasitism as a result of the introductions (Naranjo 2008). Our study was not a life table study, so the results are not directly comparable. However, in Australia parasitism in pre-release cotton averaged 3.3% and since the release now averages 34%, a 10 fold increase. Whether this increase is sufficient to deliver additional irreplaceable mortality is not known and what level of additional mortality is needed is also not known, but the initial results are promising.

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Section 2

Area-Wide Management of Silverleaf Whitefly and its Parasitoid *Eretmocerus hayati*

Area-Wide Management of Silverleaf Whitefly and its Parasitoid *Eretmocerus hayati*

Nancy Schellhorn, Anne Bourne, and Paul De Barro

Introduction

Mobile pests don't recognise field or farm boundaries. When individual farmers try to control mobile insect pests on their own farms without reference to other crops and vegetation in the surrounding landscape, it can be a frustrating experience. The same can apply when farmers want to capture the benefits of natural enemies of pests. The number and types of natural enemies that colonise their farm can be reduced if adjacent field or farms are sprayed with insecticides that kill them.

Mobile pests such as SLW are most troublesome when they arrive as crops are emerging and are vulnerable to attack. In this situation their numbers can build rapidly, particularly if there are no natural enemies around to keep the numbers down. Furthermore, the greatest suppression of pests from biological control agents occurs when the agent arrives at the same time or shortly after the pest (Settle et al. 1996; Ives & Settle 1997; Landis & van der Werf 1997; Bianchi & van der Werf 2003). Early colonisation of crops by pests and their natural enemies depends on pest and natural enemy populations in the surrounding region. This includes the number and size of the populations and the distance of these pest populations from the newly planted crop.

To understand the appropriate spatial scale for managing mobile pests and their natural enemies, we investigated the behaviour and management of silverleaf whitefly (SLW), *Bemisia tabaci* Biotype B, and its parasitoid *Eretmocerus hayati* at the field, farm and landscape level. Details of their biology and relevant scientific literature are found in the proceeding section. Our study investigated: 1) how fast SLW find a newly planted crop, 2) what proportion of the crop they infest and the heaviness of the infestation, and 3) the role of surrounding landscape in new infestations. The implications of their findings are used for considering management option for SLW and its parasitoid.

Material and Methods

Investigations were conducted in two different landscapes that were four kilometres in diameter and 20 kilometres apart, both located in the tropical coastal region around Bundaberg, QLD (Fig. 1). Although the same crops were grown in each landscape, they were grown in different proportions, the one around the Hummock being farmed much more intensively than the other one Northwest of Bundaberg. The crops in the region included those that were host to SLW: melons (rock, water, pumpkin, honey dew), sweet potato, egg plant, and those that were not hosts: sugar cane and pasture.

In order to relate the role of the surrounding landscape to colonisation rates and infestation levels of SLW and *Er. hayati*, we characterised each landscape including crop type, size, number of SLW host crops at varying distances from our experimental crops (see below), and the quality of the host crops in terms of density of SLW and *Er. hayati*. Quality of host crop was characterised by measuring the number of crops that were sources (both adult and their offspring) and sinks (either host crops yet to be colonised or with adults only). This allowed us to know the function

of each crop in the landscape and use these measures to make predictions about the role of landscapes in the process of colonisation of *SLW* and *Er. hayati*.

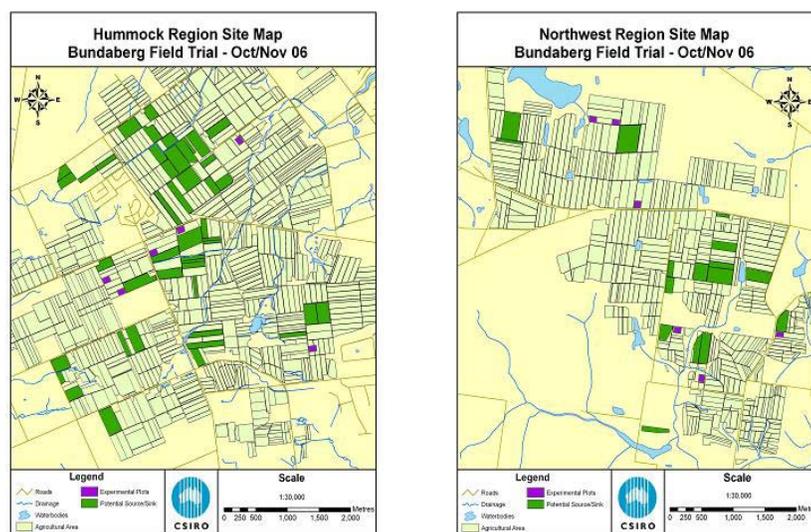


Fig. 1. Field sites in Bundaberg, QLD, at hummock region (left) and northwest (right) showing experimental plots (purple), potential *SLW* host crops (dark green), non-host crops (light green), and grazing land or residential (pale yellow).

Within each landscape there were two treatments - adjacent to a host crop with *SLW* and far from a host crop with *SLW* i.e. more than 250 meters away. Each treatment was replicated three times. We put out sentinel rock melon plants to mimic real fields (around 6,500 in total), either adjacent to a host crop with *SLW* or greater than 250 m from a host crop. The sentinel plants allow us to measure the result of adults colonising, eg. the number of eggs they lay, which has more direct implications for pest management than the number of adults that show up.

The sentinel melon plants were placed in fallow cane fields, which had cane trash lying about due to recent harvest. The sentinel melon plants were arranged as an experimental crop. Each crop measured 100 x 75 m with 20 points in a 5 x 4 design. Each point contained a module that included three melon seedlings free of pests (clean treatment), and three melon seedlings infested with nymphs of *SLW* (infested treatment). The clean treatment allowed us to evaluate colonisation and oviposition of *SLW* and the infested treatment allowed us to evaluate colonisation and oviposition by *Er. hayati*. The experimental crops were left in place for 4 days, cleared and re-set 12 hours later. This process was repeated three times over a period of 14 days, and allowed us to understand the speed and frequency of colonisation. Using fallow fields was important because it allows one to distinguish between colonisation from a surrounding landscape versus what is happening on plants within a field.

Statistical analysis was conducted by using an analysis of variance to determine whether the response variable, mean number of individuals, varied among landscapes (Hummock and Northwest) and treatments (adjacent and far). A logistic regression was used to determine whether the response variable, proportion colonised, varied among landscapes and treatments. Furthermore, a logistic regression was used to determine how each of the above listed response variables could be explained by the number and density of source and sink populations at various

spatial scale (100m, 500m, 1000m, 1500, 2000m, 2500m, 3000m, 3500m and 4000m). For example, from our landscape characterisation we knew the number of crops and density of SLW within each distance listed. This information could be used in the statistical model to understand how much variation in the response variable could be explained by the density of SLW at say 1000m.

Results

How fast do SLW and Er. hayati find a new crop?

SLW and *Er. hayati* colonise new seedlings fast and repeatedly. In both landscape SLW colonised all 12 experimental crops at each time period, meaning that colonisation of SLW happens within 4 days and every 4 days. In the Hummock, *Er. hayati* colonised all fields within 4 days and every 4 days. However, in the Northwest, *Er. hayati* did not colonise one field at time period two and one field at time period three.

What proportion of the crop do they colonise and how heavy is the infestation?

The two landscapes differed significantly. The proportion of experimental crop colonised (eg. presence or absence of SLW or *Er. hayati*) and the heaviness of the infestation (eg. the number of eggs (either SLW or *Er. hayati*) oviposited on the plants) was significantly higher in the Hummock for both SLW and *Er. hayati* (Table 1).

Table 1. The proportion and heaviness of infestation of SLW and *Er. hayati* in experimental crops (constructed using sentinel plants) in each landscape.

| Organism | Type of infestation | Hummock | Northwest | Significance |
|-------------------|-----------------------------|-------------|------------|---------------------------|
| SLW | Proportion plants colonised | 0.69 | 0.49 | F _{1,8} =5.53* |
| | Heaviness (mean ± se) | 12.9 (1.5) | 2 (0.21) | F _{1,8} =13.68** |
| <i>Er. hayati</i> | Proportion plants colonised | 0.44 | 0.17 | F _{1,8} =13.28** |
| | Heaviness (mean ± se) | 3.87 (0.42) | 1.7 (0.33) | F _{1,8} =7.22* |

*P < 0.05; **P < 0.01

Because there was a significant effect due to the landscapes, the remaining results are shown for each landscape separately.

In the Hummock, colonisation of SLW was the same regardless of whether the experimental crop was adjacent to host crops of SLW or far away (> 250 m). However, for *Er. hayati*, significantly more colonised experimental crops adjacent to host crops of SLW than far.

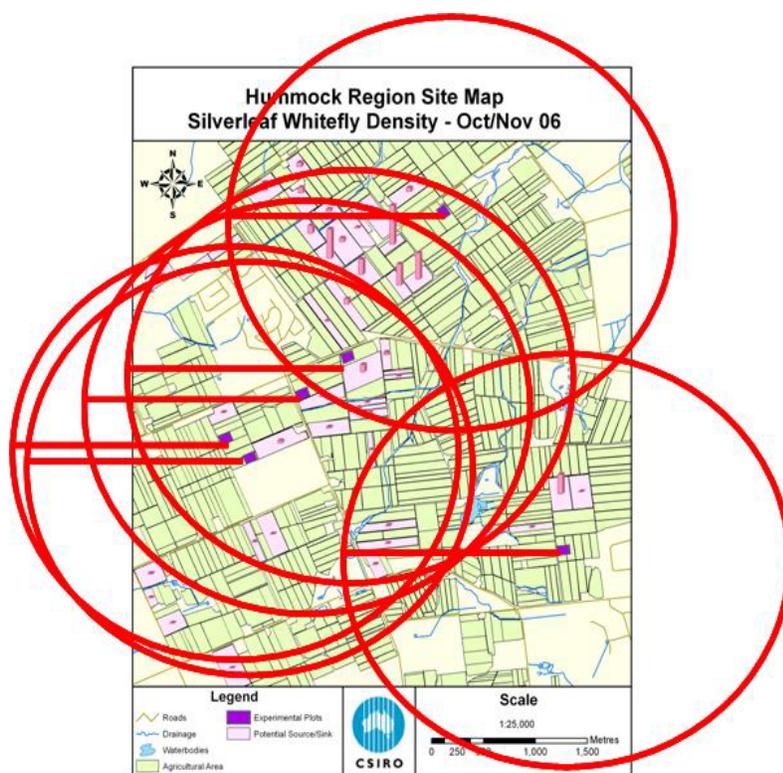
In the North, colonisation of SLW was also the same regardless of whether the experimental crop was adjacent to host crops of SLW or far away. However, there was an experimental crop x treatment interaction, where only one experimental crop adjacent to a host crop of SLW had a significantly higher proportion colonised.

What role does surrounding landscape play in new infestations?

As indicated above, the crops grown in the two landscapes were the same, but grown in different proportions. As indicated from the landscape characterisation, at the Hummock, there were 45 crops host to SLW totalling 1.7 km² of host crops resulting in ca. 4.6 billion SLW, and 254,000 *Er. hayati*. For SLW, of the 45 crops, 36 had both adults and immatures, 9 had adults only and only one was clean. For *Er. hayati*, of the 45 crops, 20 had both adults and immatures, 6 had adults only and 11 were clean. At the Northwest, there were 16 crops host to SLW totalling 0.6 km² of host crops resulting in ca. 210,139 SLW and 60 *Er. hayati*. For SLW, of the 16 crops, 2 had both adults and immatures, 12 had adults only and 2 were clean. For *Er. hayati*, of the 16 crops, 2 had both adult and immature, 0 had adults only and 14 were clean.

The Hummock

Proximity to a SLW host crop did not explain SLW colonisation, however, features of the surrounding landscape did. The proportion of the experimental crop infested can best be explained by the number of host crops of SLW at a scale of 3 kms ($X^2 = 5.14$, $P = 0.023$) (Fig. 2a). The density of SLW at a scale of 3.5 kms also explains the proportion infested, but only marginally significant. However, the heaviness of the SLW infestation can best be explained by the number of host crops of SLW within 100 m ($R^2 = 0.78$, $P = 0.0196$).



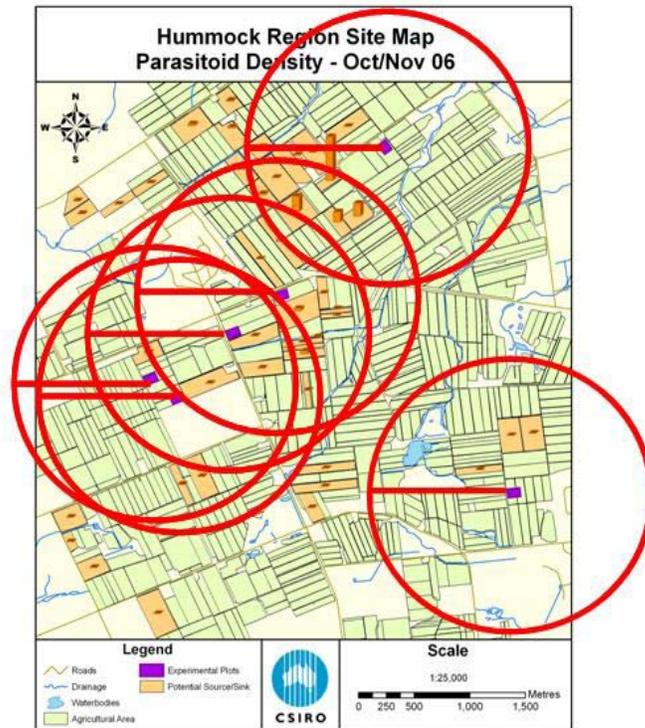


Fig. 2 a-b. The scale that best explains the proportion of crop infested by SLW (top) and *Er. hayati* (bottom) at the Hummock region.

For *Er. hayati*, the proportion of the experimental crop infested can best be explained by two things: the density of parasitoids at a scale of 2.5 km AND being adjacent to host crops of SLW (Density $X^2 = 4.24$ and $P = 0.04$, Treatment $X^2 = 7.87$ $P = 0.005$) (Fig. 2b). We were unable to predict the heaviness of parasitoid infestation.

Northwest

The proportion of the experimental crop infested can best be explained by the density of SLW at a scale of 500 m ($X^2 = 4.66$, $P = 0.03$). However, the heaviness of the SLW infestation can best be explained by the density of SLW within 100 m ($R^2 = 0.80$, $P = 0.016$).

For *Er. hayati*, we never found adult *Er. hayati* and only reared them out from two locations in the South of the landscape. However, they colonised all of our experimental crops, but not every time. This suggests that they are highly mobile and moved approximately 4 kms in 4 days.

To limit size of file and cost of printing, figures of results are not shown for all insects and landscape combinations.

Discussion

Our results show that the landscape context can greatly influence SLW and its parasitoid. For SLW, in areas with intense production and lots of SLW (eg. Hummock) the sources of SLW in the landscape (@ scale of 3km) explain the proportion of the crop infested, but sources within 100m explain whether the infestation is heavy. In areas with limited production and few SLW (eg. Northwest) the density of SLW within 0.5 km explain how much of the crop is infested, and within 100m the size of the infestation.

For *Er. hayati*, colonisation is best when there are sources of parasitoids at least within 2.5 kms and new crops are planted next to existing crops. The parasitoids most likely use plant cues to arrest further movement, and to initiate area-restricted searching as they look for hosts to parasitize.

The implication of this result is that in agricultural landscapes with intensive production and lots of SLW an area-wide approach is essential, while also suppressing on-farm levels of pests. However, in agricultural landscapes with limited production and few SLW what farmers do on-farm has the greatest impact, but an area-wide approach is beneficial. For *Er. hayati*, an area-wide approach is also essential. Given their high mobility, a refuge providing a source of *Er. hayati* could be established on-farm or at several locations within a region. The details of the refuge, for example crop type, size, seasonal variability, will be investigated in the newly funded HAL project 'Getting the most out of *Eretmocerus hayati*' (VG08051). The bottom line is that an area-wide approach is essential for both pest and parasitoid! To control SLW and get the most out of its parasitoid, communities must work together on developing their pest management plans.

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Section - 3

Technology Transfer and Extension

Technology Transfer and Extension

Industry Meetings

Grower Meetings

Bundaberg 6 Feb 2008
Chinchilla 18 Feb 2008
St George 19 Feb 2008
Gatton 5 March 2008

Publications, Handbooks, Information Leaflets

- Schellhorn N, Lawrence L (2008) The role of landscape in area wide management of silverleaf whitefly. *Australian Grain*, July-August 2008.
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Articles and Media Releases

Newspapers, magazines and electronic media

- North Queensland Register 24/7/08
 GRDC Ground Cover 1/6/2008
 Champion Post 22/2/2008
 Australian grain 25/12/2007
 Weekly Times 23/1/2008
 Australian Life Scientist 1/2/2008
 Gympie Times 30/1/2008
 News Mail 31/1/2008
 Gympie Times 13/2/2008
 News Mail 13/2/2008
 Balonne Beacon 14/2/2008
 Farming Ahead March 2008 No. 194
 National Marketplace News March 2008
 North Queensland Register 7/8/2008
 Champion Post 19/1/2007
 Fraser Coast Chronicle 21/2/2007
 Katherine Times 9/5/2007
 Weekly Times 21/11/2007
 Rural Weekly - North Central Queensland Edition 20/11/2007
 Rural Weekly insert 23/11/2007
 Gatton Lockyer Brisbane Valley Star 12/12/2007
 Australian R&D Review December, 2007
 Australian Grain Nov-Dec 2007, 20-21
 Champion Post 16/3/2007
 News Mail 3/11/2006
 Gympie Times 21/02/2007
 Australasian Science 29(5) 35-37

Radio and television

- WIN Cairns (Cairns), WIN News, 01/11/2006 06:16PM Compere: Paul Taylor
 Prime TV, Bundaberg, 7 Feb 2008

Section 4

Project Outcomes

Project Outcomes

Establishment of an effective biological control agent

In the space of 3.3 years *Er. hayati* has spread from 12 release areas along the east coast of Queensland to now cover much of the current distribution of SLW in eastern Australia. It has also established successfully in Carnarvon, WA and Alice Springs, Katherine and Darwin in the Northern Territory. There has been a six-fold increase in the average level of parasitism and an overall increase in the frequency of attack such that 76% of all collections now contain parasitised whitefly whereas previously it was 25%. The introduction of *Er. hayati* appears to have had a considerable impact on SLW. Drought which has affected much of Australia during the entire release and post-release period covered by this study may have contributed to the decline in SLW abundance in some areas through the reduction in cropping. However, the decline in SLW numbers in places such as Bundaberg which have so far escaped drought are equivalent to those observed in drought affected areas.

Our results also show that the landscape context can greatly influence SLW and its parasitoid. The implication of this result is that in agricultural landscapes with intensive production and lots of SLW an area-wide approach is essential, while also suppressing on-farm levels of pests. However, in agricultural landscapes with limited production and few SLW what farmers do on-farm has the greatest impact, but an area-wide approach is beneficial. For *Er. hayati*, an area-wide approach is also essential. Given their high mobility, a refuge providing a source of *Er. hayati* could be established on-farm or at several locations within a region. The bottom line is that an area-wide approach is essential for both pest and parasitoid! To control SLW and get the most out of the parasitoid that attacks it, communities must work together on developing their pest management plans.

Recommendations

1. *Eretmocerus hayati* has been extraordinarily successful in establishing and spreading. Additional research that determines how best to manipulate *Er. hayati* at the field, farm and landscape scale should be funded now to maximise the return to growers.

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