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Establishment of *Chilocorus* spp. (Coleoptera: Coccinellidae) in a *Carica papaya* L. orchard infested by *Aonidiella orientalis* (Newstead) (Hemiptera: Diaspididae)

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Abstract Releases of two coccinellid predators, (*Chilocorus baileyi* (Blackburn) and *Chilocorus circumdatus* Gyllenhal, of oriental scale (*Aonidiella orientalis*) onto papaya resulted in successful establishment of the predators with a new generation being produced. Both coccinellids took 5 weeks from egg to adult in the field. Use of the coccinellids offers a potential control method for this scale on the few occasions when the established parasitoids fail to control the scale and scale numbers become large on limited numbers of papaya trees.

Key words *Aonidiella orientalis*, biological control, *Carica papaya*, *Chilocorus* spp.

INTRODUCTION

Two successful hymenopterous parasitoids for control of oriental scale, *Aonidiella orientalis* (Newstead), on papaya are available in Queensland (Elder *et al.* 1998). One of these, *Encarsia citrina* (Craw), occurs naturally in most oriental scale populations where it usually parasitises at least 80% of the second-instar scales. The other, *Comperiella lemniscata* Compete and Annecke, was imported from southern China and released in January 1991 (Elder *et al.* 1998). It parasitises third-instar scales and has proved successful in controlling scale which have escaped parasitism by *E. citrina*.

In spite of the parasitoids reducing populations to below economic threshold for lengthy periods, scale outbreaks on individual trees or small groups of trees can still occur. Scale numbers tend to increase each year from March/April to reach a peak by July and then decline rapidly (Elder *et al.* 1998). These outbreaks can be large enough to kill trees or at least cause loss of fruit production. More than 10 scales on the blossom end of a fruit makes it unsaleable. Once scale numbers build up on the trunks of trees to medium levels of 10/cm^2, crawlers start to appear on the lower older fruit.

A number of predatory coccinellid beetles have been found feeding on oriental scale (Elder *et al.* 1998). This study was undertaken at Yarwun (24°S, 151°E) to determine whether two of the coccinellids (*Chilocorus baileyi* (Blackburn) and *Chilocorus circumdatus* Gyllenhal) could be established on *A. orientalis* in the field. *Chilocorus circumdatus* was being investigated for control of a number of scale insects and is readily reared in the laboratory (Houston 1991; Smith *et al.* 1995). *Chilocorus circumdatus* has the advantage that it can be bought commercially from 'Bugs for Bugs' at Mundubbera, Queensland, Australia (D. Papacek, pers. comm.).

MATERIALS AND METHODS

The two coccinellids used in releases were from populations reared on *Aspidiotus nerii* Bouché (Smith *et al.* 1995). However, previous to this study *A. orientalis* was found to be a host in the field (Elder *et al.* 1998) and the coccinellids collected in the field were reared through 11 generations on *A. orientalis* in the laboratory at 26°C and 50% relative humidity (RH).

Beetles were released on marked trees up to 2.5 m in height at between 500 and 1250 beetles/ha. Since papayas are planted at 2500 trees/ha, the release rate was about 10 predators to every 30 trees. This is about the same rate/ha as in the citrus industry where predators are released at 30 to every ninth tree, with a tree planting rate of 250/ha (Papacek, pers. comm.) (Table 1). The trees were distributed throughout the plantation and were chosen on the basis that they had an evenly spread scale population of at least 10/cm^2 over the trunk. This was a medium population level, with 30 scales/cm^2 and above regarded as a high infestation. The release sites varied considerably in their exposure to wind and only at site 2 with windbreaks was there a well-developed canopy over the whole area (Table 1). The small number of scale-infested trees within any restricted area and the mobility of the predators did not allow matching control (no predator release) areas to be selected.

Table 1 Predator release details, time (weeks) to first increase in numbers of larvae, pupae and adults of *Chilocorus* spp. after field release of adults and highest total *Chilocorus* spp. and scale numbers reached (all life-history stages) per tree at four sites.

Site	Predator species and release date	No. trees and area (ha)	No. predators per tree	Week to first record of predator life-history stage: Larvae	Pupae	Adults	Av. max no. predators	No. scales/cm^2
1	*C. baileyi* 5 May 1993*	29 (0.4)	10	3	4	5	3.5 ± 2.4	13.9 ± 3.0
2	*C. baileyi* 2 March 1994†	25 (0.6)	20	2	4	5	12.8 ± 8.0	16.1 ± 3.9
3	*C. baileyi* 2 March 1994*	25 (0.4)	20	3	4	5	60.2 ± 11.5	44.3 ± 3.0
4	*C. circumdatus* 17 March 1994	10 (0.2)	10	3	5	5	26.2 ± 12.3	35.9 ± 9.9

Average total ± SE are presented for maximum predator numbers per tree 5 weeks after release and number of scale/cm^2 at the time of release of the predators. The area (ha) is the area of papayas and not the much smaller area infested with scale as the scale showed a very patchy distribution.
*Exposed, same site; †wind breaks.

The numbers of first-, second- and third-instar scales (Elder & Smith 1995) were counted weekly for up to 9 weeks on each of the marked trees in five, 1 cm^2 areas per tree at approximately 1.5 m above ground level. The five, 1 cm^2 areas were 2 cm apart vertically (on the same side of the tree) and the scales on same (marked) areas were counted each week. The numbers of larvae, pupae and adults of *C. baileyi* or *C. circumdatus* were also counted each week but were counted on the whole tree trunk and lower fruit because their numbers were much lower than the scale, and they were easier to find and count.

The relationship between *Chilocorus* spp. and *A. orientalis* populations over each sampling period was investigated by means of linear regressions with 0, 1, 2, 3, 4, 5 and 6 weeks lag between release of the predators and scale counts. In addition, the relationship between the size of the scale population at predator release and the maximum total predator population was investigated by means of correlations of the raw and log-transformed data.

At site 1, there were 25 release trees in one area and 25 trees in an adjacent non-release area both monitored weekly. An additional 25 trees were assessed at the end of the experiment. These were trees in the release area of trees on which releases had not been made. At sites 2, 3 and 4 only release trees were monitored as there was no suitable non-release area.

RESULTS

Neither *C. baileyi* nor *C. circumdatus* was found at any site prior to the releases. The lepidopterous scale predator, *Batrachedra arenosella* (Walker) (Batrachedridae), was common throughout the four release sites and on some trees its larvae ate all the scale in the sampling positions. These trees were not used. At all four release sites the coccinellids readily climbed onto the trees from their containers and commenced feeding on oriental scale despite having been reared on *A. nerii*.

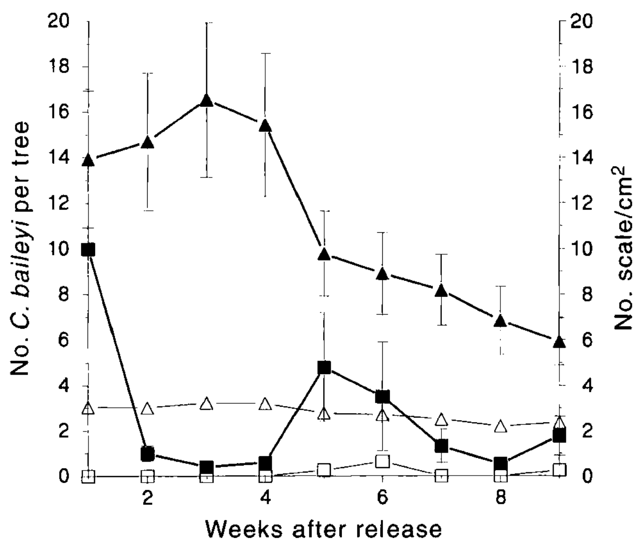

Fig. 1. Average total number of *Chilocorus baileyi* (all life-history stages) per tree and total scales/cm^2 on non-release and release trees from 5 May 1993 at site 1: -■-, total *C. baileyi* release area; -▲-, total scale release area; -□-, total *C. baileyi* non-release area; -△-, total scale non-release area. The error bars represent ± 1 SE.

At site 1, *C. baileyi* established on the release trees and went through at least one generation in 5–6 weeks (Table 1) during the mild weather of winter. Larvae were first found after 3 weeks and pupae after 4 weeks. Numbers peaked after 4 weeks averaging 4.5/tree (adults, larvae and pupae combined) (Fig. 1). Only small numbers (average of 0.6 per tree 6 weeks after the start) of *C. baileyi* were found in an adjacent area where no releases were made (Fig. 1).

Correlations and lagged regression analyses between total scale counts (all instars) and total *C. baileyi* counts (combined larvae, pupae and adults) were not significant ($P > 0.05$).

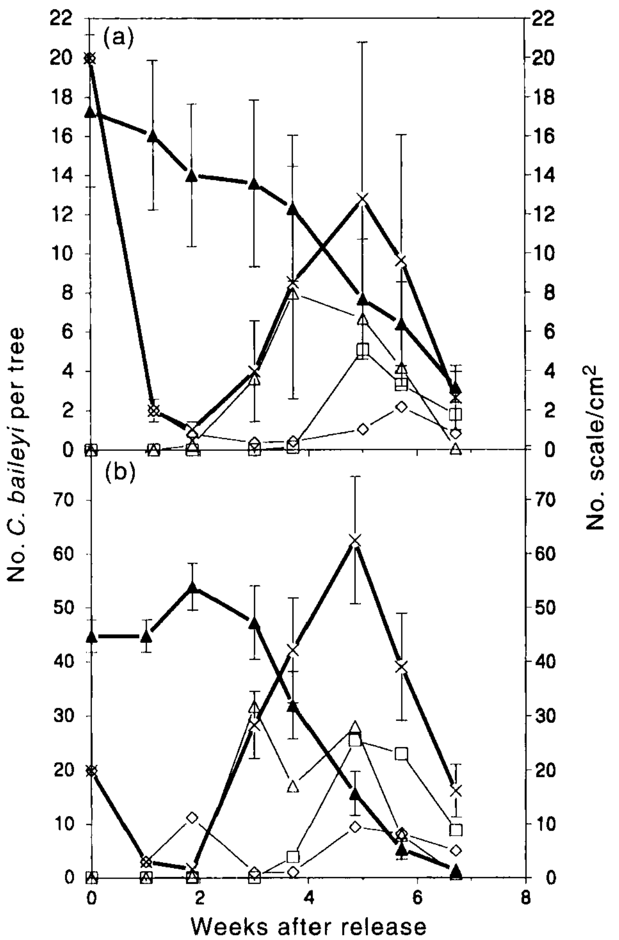

Fig. 2. Average number of *Chilocorus baileyi* (all life stages and total) per tree and total scales/cm^2 on release trees from 3 March 1994 at sites 2 and 3: -◇-, adults; -□-, pupae; -△-, larvae; -×-, total *C. baileyi*; -▲-, total scales. The error bars represent ± 1 SE.

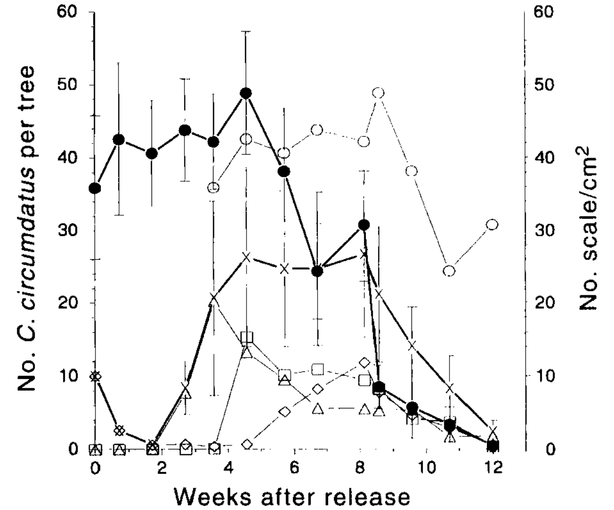

Fig. 3. Average number of *Chilocorus circumdatus* (all life-history stages and total) per tree and total scales/cm^2 on release trees from 17 March 1994 at site 4: -◇-, adults; □, pupae; -△-, larvae; -×-, total *C. circumdatus*; -●, total scales; -○-, total scales, 4-week lag. Scale numbers are shown both on the actual days recorded and lagged by 4 weeks. The error bars represent ± 1 SE.

Our casual observations indicated that the beetles spread rapidly throughout the release area (onto non-release trees previously without adults) within 2 weeks of release. This coincided with a decrease in the number of adults per tree. A count on an additional 25 trees throughout the release area at the completion of the study (9 weeks after start) indicated that the predator was present at an average of 0.3 per tree compared with 1.8/tree on the release trees.

Scale numbers on the release trees declined over the period of the study (Fig. 1) so that by the last count (28 June) there was an average of 1.8, 2.4 and 1.7 first-, second- and third-instar scales/cm^2, respectively. There was an average of 5.9, 2.8 and 2.4 first-, second- and third-instar scales on 25 non-release trees in the release area, which was consistently higher for all instars than for the release trees. Scale populations in a separate nearby area where no releases had been made did not decline, although populations were much lower at the start (Fig. 1).

At site 2, *C. baileyi* established on the release trees in an area protected by windbreaks and went through one generation, indicated by an increase in numbers of adults, in 4–5 weeks (Fig. 2) under warm autumn conditions. Larvae were first found after 2 weeks and pupae after 4 weeks. Numbers peaked after 5 weeks averaging 12.8 per tree (adults, larvae and pupae combined) (Table 1).

Correlations and lagged regression analyses between total scale counts and total *C. baileyi* counts were not significant ($P > 0.05$).

At site 3, *C. baileyi* established on the release trees and went through at least one generation in 4–5 weeks (Fig. 2) under warm autumn conditions. Larvae were first found after 3 weeks and pupae after 4 weeks (Table 1). Numbers peaked after 4 weeks averaging 62.9/tree (adults, larvae and pupae combined). Eight weeks after release there was an average of 9.0 *C. baileyi* per tree on both the release and non-release trees. The beetles released in the previous May did not persist over winter on this exposed site.

Correlations and lagged regression analyses between total scale counts and total *C. baileyi* counts were not significant ($P > 0.05$).

At site 4, *C. circumdatus* established on the release trees and went through at least one generation in 6 weeks (Fig. 3) under autumn conditions. Larvae were first found after 3 weeks and pupae after 5 weeks. Populations peaked after 5 weeks averaging 26.3 per tree (adults, larvae and pupae combined) (Table 1).

Regression analyses between total scale counts (all instars) and total *C. circumdatus* counts gave correlation coefficients (r) of 0.87 for a 3-week lag and 0.86 for a 4-week lag ($P < 0.05$) (i.e. scale populations decreased with a lag of 3–4 weeks behind *C. circumdatus* populations)

(Fig. 3). Regressions of all combinations of the three scale and *C. circumdatus* life-history stages and totals gave lower or similar values for *r* or in the case of second-instar scales gave higher *r* values (up to 0.96) but with a longer lag period of 6 weeks. Correlations were not significant ($P > 0.05$).

DISCUSSION

Laboratory rearing indicated that *A. orientalis* was a suitable long-term host for *C. circumdatus* and the study indicated that *C. baileyi* and *C. circumdatus* could be readily established in an area moderately to heavily infested with *A. orientalis* by the release of 290–500 adults and 100 coccinellid adults, respectively. These adults fed on the scale, laid eggs and their larvae and pupae survived to produce a new generation.

The development time of 5 weeks from egg to adult for *C. circumdatus* obtained in this study was similar to that obtained by Smith *et al.* (1995) in the laboratory (i.e. at 18.6°C [37–43 days] and 22.0°C [30–31 days]). The data for *C. baileyi* obtained in this study indicate a similar temperature/time relationship (Table 1).

There was a number of confounding factors in determining the effect of *Chilocorus* spp. on the oriental scale population. The parasitoids (*C. lemniscata* and *E. citrina*) and the predator *B. arenosella* were present and would have had an effect on the scale populations. Because of the very large numbers of scale on a tree, only a restricted area was sampled ($5\,cm^2$), while the area sampled for *Chilocorus* spp. was the whole tree trunk and lower fruit. This difference may have resulted in the poor linear relationship between scale numbers and numbers of *Chilocorus* spp. However, in all cases, the scale populations declined substantially (Figs 1–3) at a time when scale numbers are usually increasing (Elder *et al.* 1998). The relationship was difficult to test statistically because while the scale populations tended to decline over most sampling periods, the coccinellid populations went through three phases at all four sites. Initially, they declined substantially in the week after release through dispersal. The coccinellids then increased after 1–3 weeks as first larvae and then pupae and new adults appeared (Figs 2, 3). This increase was followed by another decrease as the adults matured and dispersed from about 5 weeks onwards. At site 1, there was evidence of a further (fourth) phase as the number of coccinellids increased at week 9 (Fig. 1).

The use of control areas (where no predators were released) to obtain comparative data on scale numbers was not possible because of the extremely limited number of 200 trees affected over a small area (0.08 ha) and/or scattered nature of the scale outbreaks. It was found impossible to properly match areas so that they had similar scale numbers and their close proximity allowed the coccinellids to move into the non-release area (Fig. 1).

At each of the four sites, 5 weeks after release of the coccinellids, there was an average increase of 0.5, 0.6, 3.1 and 2.6 times, respectively, over the initial release numbers of the predator population on the release trees (i.e. at site 1 where 10 adults were released there was an average of five coccinellids presumably reared on each release tree whereas prior to release there were none). This does not take into account the increase in numbers of predators on the non-release trees in the release area. At site 1, where this increase was monitored, 25 trees had an average of 0.3 coccinellids per tree after 9 weeks and there was also an increase in the non-release area (Fig. 1).

In view of the successful establishment of the predators with all four releases and the resultant high numbers reached (Table 1) releases should be useful in reducing scale numbers in commercial plantations where scale populations have reached moderate levels ($10/cm^2$). Papaya growers have successfully released *C. circumdatus* at Yarwun and observed a large increase in the next generation of adults following the appearance first of larvae and then of pupae.

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REFERENCES

Elder RJ & Smith D. 1995. Mass rearing of *Aonidiella orientalis* (Newstead) (Hemiptera: Diaspididae) on butternut gramma. *Journal of the Australian Entomological Society* **34**, 253–254.

Elder RJ, Smith D & Bell KL. 1998. Successful parasitoid control of *Aonidiella orientalis* (Newstead) (Hemiptera: Diaspididae) on *Carica papaya* L. *Australian Journal of Entomology* **37**, 74–79.

Houston KJ. 1991. *Chilocorus circumdatus* Gyllenhal newly established in Australia and additional records for *Coccinella undecimpunctata* L. (Coleoptera: Coccinellidae). *Journal of the Australian Entomological Society* **30**, 341–342.

Smith D, Papacek D & Smith N. 1995. Biological control of citrus snow scale, *Unaspis citri* (Comstock) (Homoptera: Diaspididae) in south-east Queensland, Australia. *Israel Journal of Entomology* **29**, 253–260.

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