Israel Journal of Entomology

Vol. XXIX (1995) pp. 253-260

BIOLOGICAL CONTROL OF CITRUS SNOW SCALE, *UNASPIS CITRI* (COMSTOCK) (HOMOPTERA: DIASPIDIDAE) IN SOUTH-EAST QUEENSLAND, AUSTRALIA

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ABSTRACT

Citrus snow scale, *Unaspis citri* (Comstock) (Homoptera: Diaspididae) has been a major pest of citrus in eastern Australia, only partially under biological control and difficult to control with pesticides. Between 1977 and 1988, five parasitoid species were introduced (all south-east Asian in origin) but none successfully controlled the scale. In 1990, the ladybird *Chilocorus circumdatus* Gyllenhal (Coleoptera: Coccinellidae) was first observed in Queensland feeding on *U. citri*. During 1990-1991, it was field collected and laboratory reared, released and established in citrus areas throughout Queensland. *C. circumdatus* gave good control of the scale in most cases within two years of establishment. Ladybird numbers averaged 20 per tree in subcoastal orchards and about 5 per tree in coastal orchards (with lower scale infestations). Populations in some heavily infested orchards were estimated at up to 1000 ladybirds per tree. The ladybirds were persistent and there usually remained a few per tree even when the scale was reduced to a low level. The biology of the ladybird is discussed and other control agents of *U. citri* listed.

KEYWORDS: Diaspididae, *Unaspis citri,* citrus, *Chilocorus circumdatus.*

INTRODUCTION

Citrus snow scale, *Unaspis citri* (Comstock) (Homoptera: Diaspididae) occurs in all citrus areas of Queensland and in coastal New South Wales. It is south-east Asian in origin but is a serious citrus pest only in eastern Australia and Florida. It infests all above-ground parts of the tree, but most commonly the trunk and main limbs. The male scale covering is white, and heavy infestations give the trunk a snowy or white-washed appearance. In such infestations, leaf drop, twig dieback and bark splitting occur.

At commencement of this study, the main natural enemies of *U. citri* in Queensland were the parasitoid *Encarsia* sp. (*citrinal*) (Hymenoptera: Aphelinidae) (mainly in second-instar scales) and the scale-eating caterpillar *Batrachedra arenosella* (Walker) (Lepidoptera: Noctuidae). These beneficial insects although useful were unable to give satisfactory control of the pest either in orchards or home gardens.

Chemical control of *U. citri* in Queensland after the Second World War was with lime sulphur, then increasingly with organophosphate insecticides. During the 1970s methidathion

became the most applied insecticide. Thorough coverage using an oscillating boom was necessary to achieve good control. The sprays were costly, very disruptive to beneficial insects and increasingly ineffective, as resistance developed.

With the rapid expansion of Integrated Pest Management (IPM) in Queensland orchards from the late 1970s, improved biological control was vital and a program to import parasitoids began in 1977. Three strains of *Aphytis lingnanensis* Compere (Hymenoptera: Aphelinidae) were introduced: the first (HK1), originating in Hong Kong, was introduced from Florida in 1977; the second (HKJ) was introduced from Japan in 1980; the third was introduced from Thailand in 1988. These were all mass reared and a total of 0.5–2 million of each released. HK1 and HKJ were both recovered but mostly from scale on leaves and fruit and their impact was negligible. The Thai strain was the most successful and formed part of this study.

Searches for other parasitoids were also made in southern Guangdong province (China) during 1983–1988 and two parasitoid species collected: *Aphytis gordoni* DeBach and Rosen (Hymenoptera: Aphelinidae) and *Encarsia inquirenda* (Silvestri) (Hymenoptera: Encyrtidae). Both were imported but in very small numbers and while *A. gordoni* was recovered for one or two generations from a caged tree, neither successfully established (Smith and Papacek, 1993).

The ladybird *Chilocorus circumdatus* Gyllenhal (Coleoptera: Coccinellidae) was first observed in Queensland in 1990, feeding on *U. citri* (Houston, 1991; Smith and Papacek, 1991). Previous unsuccessful attempts had been made to introduce it to western Australia in 1902 and in 1960–1963 for control of California red scale, *Aonidiella aurantii* (Maskell) and San José scale, *Quadraspidiotus perniciosus* (Comstock) (Homoptera: Diaspididae). It is Oriental in origin, recorded preying on diaspidid species such as *Aspidiotus destructor* Signoret, but not previously from *U. citri*. It was not observed feeding on *U. citri* in southern Guangdong by the senior author during the 1980s. The beetle was collected from the field, reared in the laboratory on oleander scale, *Aspidiotus nerii* Bouché on butternut pumpkins and disseminated during 1990–1991 throughout the citrus areas of Queensland.

This study was carried out during 1990–1993 to evaluate the impact of the various parasitoids and predators, particularly of *C. circumdatus*, on *U. citri* populations in citrus groves of Queensland.

MATERIALS AND METHODS

Unaspis citri: Orchard Studies

The studies were carried out at Beerwah (27°S, 153°E), Eidsvold and Mundubbera (26°S, 151°E) in Queensland, Australia.

At Beerwah, the study sites were a 4-ha block of 20-year-old Meyer lemons, a 4-ha block of 15-year-old Late Valencia oranges, a 0.5-ha block of 10-year-old Siletta oranges and a 0.5-ha block of 15-year-old Joppa oranges. Releases of the *A. lingnanensis* strain from Thailand began in April 1989 and continued at regular intervals until April 1990. About 4000 adults were released per block on each occasion totalling at least 50000 per block over 12 months. Releases of *C. circumdatus* began in March 1990 and totalled about 500 adults per block over 2–3 months.

Ten samples of scale-infested bark (2 cm wide, 10 cm long) were cut, one from each of ten randomly selected trees at approximately monthly intervals from 1989 to 1993. Under a binocular microscope, 20–40 consecutive adult female scales were assessed as live, dead or

parasitised. Observed predators or pathogens were recorded. On 8 occasions (from April 1989 to November 1993) the scale populations were rated on 20 random trees using the following system: 0, no scale; 1, trace of scale on the trunk or on one of the limbs; 2, scale more evident on the trunk and limbs but in low population with few on the leaves or fruit; 3, scale on most parts of the tree including fruit but not heavy enough to cause bark splitting or leaf drop; 4, heavy infestation, trunk and limbs white in appearance, some bark splitting and leaf drop; 5, very heavy infestation with noticeable bark splitting, leaf drop and dieback. From mid-1990 to November 1993, on 9 occasions an assessment was made of *C. circumdatus* numbers. Adults were counted for 30 seconds on each of the above mentioned 10 bark-sampled trees.

At Eidsvold the study site was a block of 315 trees of 20-year-old Washington Navel oranges (7 rows, 45 trees per row). Fifty trees (every third tree in every second row) were tagged and sampled at approximately 1–2-month intervals during 1990–1993. The *A. lingnanensis* strain from Thailand was released (20000 adults) during March–April 1989, and *C. circumdatus* (500 adults) in January 1990. The numbers of *C. circumdatus* (adults, larvae and pupae) were recorded during a 30-second observation per tree; the scale populations were rated on each of the 50 trees (as described above for Beerwah) on 13 occasions and a single bark sample (2 × 10 cm) was cut off each of 20 of the tagged trees on 12 occasions (the same tree on each occasion). The bark sample was examined under a binocular microscope and the percentage of live adult female scales and parasitism assessed. The number of crawlers present on 1 cm^2 (randomly selected) was also recorded. Note was made of incidence on the trees of the predator *B. arenosella.*

At Mundubbera the study site was a block of 300 trees of 10-year-old Washington Navel oranges (10 rows, 30 trees per row). Fifty trees were tagged as at Eidsvold (see above) and similar samples taken. Releases of the *A. lingnanensis* strain from Thailand (about 25000 adults) were made during March–April 1989. Five hundred *C. circumdatus* adults were first released in January 1990.

Chilocorus circumdatus: Laboratory Studies

Two sources of *C. circumdatus* were used: field-collected beetles feeding on *U. citri* on citrus at Mundubbera and laboratory reared beetles at Maroochy Horticultural Research Station (MHRS), Nambour (27°S, 153°E). The laboratory beetles were reared on *A. nerii* at 25°C and 60% RH.

Life history. To determine the number of instars for *C. circumdatus,* measurements were made on 110 randomly selected larvae of the head capsule width and body length using a micrometer eyepiece in a binocular stereo microscope. Observations were also made on a dozen larvae from hatching to pupation recording the number of moults at 25°C.

The duration of each stage was measured at six temperatures (14.4, 18.6, 22.0, 25.0, 29.0 and 31.0°C) in a multi-temperature incubator. Ten scale-infested butternut pumpkins were each exposed to approximately 20 adult beetles for 24 hours, the beetles removed, the pumpkins placed in the incubator and the development of the various stages recorded daily.

The pre-oviposition period and adult longevity were measured at temperatures of 18.6, 22.0, 25.0, 28.0 and 31.0°C. Lots of 25 freshly emerged beetles were placed on a scale-infested pumpkin in an individual cage and measurements taken of time to oviposition and adult longevity.

RESULTS

Unaspis citri: Orchard Studies

The results from one of the Beerwah sites (in Meyer lemons) are shown in Fig. 1, those from the Eidsvold site in Fig. 2 and those from Mundubbera in Fig. 3.

On Meyer lemons at Beerwah (Fig. 1) the parasitism rate by the *A. lingnanensis* from Thailand peaked at 39.4% in May 1989, but in 1989, 1990 and 1993 only ranged 8–12% and in 1991 and 1992 it was less than 1%. *Encarsia* sp. was the dominant parasitoid in second-instar scales. In adult females, it averaged only 8% over the 4 years. *C. circumdatus* was first recorded in August 1990 and by July 1991 an average of 10 beetles per tree were recorded. The population of *C. circumdatus* remained at this level until 1993 when the average dropped to about 1 beetle per tree. The percentage of live scale dropped from an average 42.3% in 1989–1990 to 7.5% during 1991–1993. The density rating of the scale dropped from a maximum 3 in April 1989 to 1 by July 1991 and finally 0.5 at the conclusion of the study. A similar pattern was followed at the remaining Beerwah sites.

The predator *Batrachedra arenosella* occurred in moderate numbers in all four blocks, attacking *U. citri* on 10–20% of the trees during summer–autumn especially in 1989 and 1990 when scale infestations were highest. Other predators included *Telsimia* sp. (Coleoptera: Coccinellidae) (present on occasions in low numbers on up to 25% of the trees), *Rhyzobius* sp. (Coleoptera: Coccinellidae) and *Cybocephalus* sp. (Coleoptera: Nitidulidae). The mite *Hemisarcoptes* sp. (Astigmata: Hemisarcoptidae) was associated with a significant level of unexplained scale mortality in early July 1989 and early August 1990. During wet weather, scale mortality was higher and there was a high incidence of fungal attack (*Aschersonia* sp.). The wet humid conditions at the Beerwah sites especially from January to April resulted also in heavy lichen and moss growth on the trunk and main limbs with increased competition for settling sites for the scale.

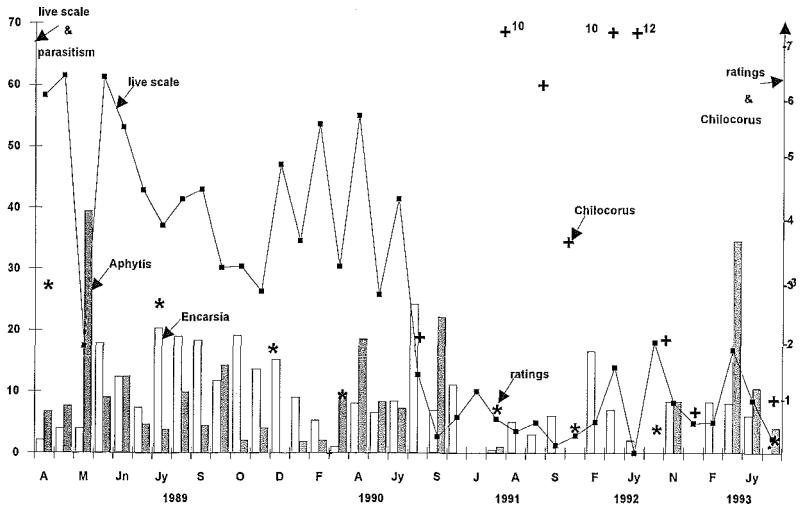

Fig. 1. *Unaspis citri* population ratings (*), % live adult female scales, parasitism levels of *Aphytis lingnanensis* and *Encarsia* sp. and numbers of *Chilocorus circumdatus* (+) (adults, larvae and pupae recorded in a 30-second count per tree) in Meyer lemons at Beerwah, 1989–1993.

At Eidsvold the initial scale infestation was high (average rating 4). Levels of the *A. lingnanensis* from Thailand never exceeded 1–2% on twigs and practically no parasitism was recorded on the trunk. *Encarsia* sp. was present at levels of 1–2% in adult females. Because of the low levels, parasitism by both species is not shown in Fig. 2.

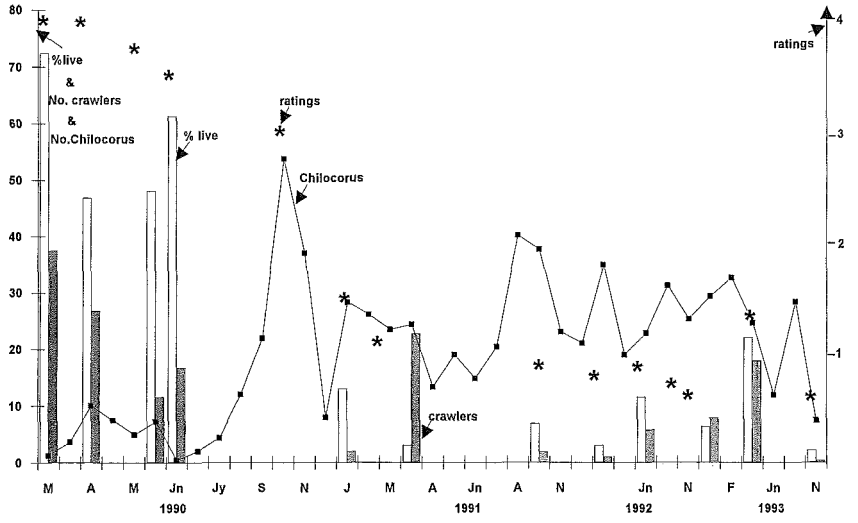

Fig. 2. *Unaspis citri* population ratings (*), % live adult female scales, numbers of scale crawlers per cm^2 and numbers of *Chilocorus circumdatus* (+) (adults, larvae and pupae recorded in a 30-second count per tree) in Washington Navel oranges at Eidsvold, 1990–1993.

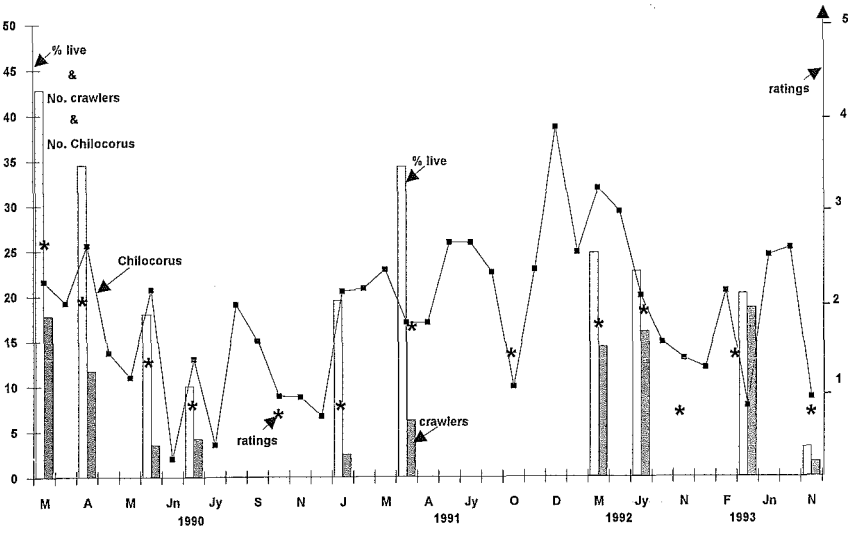

Fig. 3. *Unaspis citri* population ratings (*), % live adult female scales, numbers of scale crawlers per cm^2 and numbers of *Chilocorus circumdatus* (+) (adults, larvae and pupae recorded in a 30-second count per tree) in Washington Navel oranges at Mundubbera, 1990–1993.

C. circumdatus was first recorded at this site in March 1990. The average number per tree increased to a peak of 53.7 in October 1990 and remained above 20 for most of the study. The percentage of live scale dropped from a peak of 61.3% in June 1990 to 2.1% in November 1993. The number of crawlers per cm^2 peaked at 37.4 in March 1990 and dropped to 0.3 in November 1993. The scale population rating at conclusion of the study was 0.8. Low to moderate numbers of *B. arenosella* and the predatory beetles *Telsimia* sp. and *Rhyzobius* sp. were observed on 10–20% of the trees during the period of the study.

At Mundubbera the initial scale infestation was lower than at Eidsvold with a rating of 2.6 and 42.8% live scale. *A. lingnanensis* from Thailand and *Encarsia* sp. occurred at low levels similar to Eidsvold and again are not shown (in Fig. 3). *C. circumdatus* peaked at 42.6 beetles per tree in December 1991 and averaged 15 per tree throughout the study period. Live scale dropped to 3.2% by November 1993 and the scale rating to 0.9. The number of crawlers per cm^2 dropped from 17 in March 1990 to 2 in January 1991 but rose again in the autumns of both 1992 and 1993 before dropping to 1.6 in November 1993.

Low to moderate numbers of *B. arenosella* and the predatory beetles *Telsimia* sp. and *Rhyzobius* sp. occurred as at Eidsvold.

Chilocorus circumdatus: Laboratory Studies

Life history. Eggs are cylindrical in shape: 1 mm long, 0.5 mm in diameter. Continuous observation on the development of a dozen larvae showed there were three larval moults. Measurements on 110 larvae also confirmed this with head capsule widths grouped 0.28 to 0.4 mm, 0.44 to 0.64 mm, 0.68 to 0.84 mm and 0.88 to 1.12 mm. The corresponding body lengths were 1 to 2 mm, 2 to 3.4 mm, 3.7 to 5.5 mm and 6 to 9.2 mm. Adults and pupae are 4 to 6 mm long.

The duration of development of egg, larva and pupa is shown in Table 1. Eggs and larvae did not develop below 11.8 or above 35°C. Minimum development time from egg to adult was

TABLE 1
Duration of development (in days) of egg, larva and pupa, pre-oviposition period and adult longevity of *Chilocorus circumdatus* at different temperatures

	Temperature (°C)					
Development stages	14.4	18.6	22.0	25.0	29.0	31.0
Egg	16–19	10	8	7–8	5	5
Larva 1	5–6	3–4	2–3	1–2	1	1
Larva 2	6–7	4–5	3	2	2	2
Larva 3	7–8	4–6	3	3	3	2–3
Larva 4	7–8	4–6	4	3–4	3–4	3
Larval instars	25–29	15–21	12–13	9–11	9–10	8–9
Pupa	23	12	10	7–9	5–6	5–6
Egg to adult	64–71	37–43	30–31	23–28	19–21	18–20
Pre-oviposition	—	14–16	10–12	10–12	10–12	10–12
Egg to egg	—	51–59	40–43	33–40	29–33	28–32
% adults alive						
after 4 weeks	—	90	60	60	50	50
after 8 weeks	—	65	40	40	15	15

18 to 20 days at 31°C. There was considerable mortality in first-instar larvae at a constant 31°C and poor survival of pupae at a constant 14.4°C. The pre-oviposition period at 22.0, 25.0, 29.0 and 31.0°C was 10 to 12 days. The minimum time from egg to egg was 28 days. Adult longevity was reduced at high temperatures, e.g. survival rate was 50% after four weeks at 29 and 31°C, in contrast to 90% survival at 18.6°C.

DISCUSSION

The *Aphytis lingnanensis* from Thailand showed promise at times during 1989 and 1990 at Beerwah, especially in the Meyer lemon and Siletta orange blocks. However, as in the case of earlier introductions (HK1 and HKJ), the parasitoid was not persistent in scales on the trunk and main limbs and was not a major factor in reducing scale populations. It was even less persistent in subcoastal orchards at Eidsvold and Mundubbera. In the future, its contribution (and that of allied *Aphytis* spp.) cannot be ignored, as parasitism levels up to 50% were occasionally observed in scale on the fruit and leaves. Similarly *Encarsia* sp. cannot be discounted as it caused up to 50% mortality of second-instar scale.

Chilocorus circumdatus was the dominant natural enemy in the six study blocks and the main agent responsible for the decline in serious infestations to satisfactory levels in all cases. Beetle numbers were related to scale densities as evidenced by the higher populations in subcoastal orchards. Beetle numbers of up to 1000 per tree have been observed on heavily infested trees. Once the infestation had been reduced to a negligible level, beetle counts dropped to 1 or 2 per tree. *C. circumdatus* tends to persist, albeit at low numbers, even when *U. citri* numbers are low. This is in contrast to many density-dependent predatory coccinellids which tend to be abundant when the host is numerous while absent when host numbers are low. In coastal areas, scale and beetle numbers were low and the reduction in scale numbers tended to be less dramatic and to take longer.

At Mundubbera, the beetle was observed to be susceptible to pesticide drift. The study block was surrounded by other citrus blocks and in the summers of 1991–1992 and 1992–1993, methidathion was applied with an oscillating boom at least once to some of these blocks. Spray drift onto outside trees of the trial site reduced beetle numbers resulting in a resurgence of the scale and heavy crawler production in the autumn of these seasons. By November 1993 crawler production had subsided again to 2 per cm^2.

C. circumdatus has been established throughout all the main citrus areas of Queensland since 1990 and the status of *U. citri* has dropped from extremely serious to subeconomic levels in most orchards. Orchards where entire blocks of trees were white with the infestation now usually experience satisfactory control. During 1990 and 1991, the troublesome habit of young scale moving on to maturing fruit in March–April was controlled. The much improved level of biological control of *U. citri* achieved since 1990 has resulted in an increase from about 50 to 80% in the area of citrus adopting IPM.

It is evident that while *C. circumdatus* is able to control *U. citri* in both coastal and subcoastal areas, any factors seriously depressing the beetle population will result in fresh outbreaks of the scale. Some such factors include pesticide drift, reduction in beetle numbers following bait spraying for Queensland fruit fly *Dacus tryoni* (Froggatt) (Diptera: Tephritidae) and infestation of larvae and pupae during wet spells by the fungus *Beauvaria bassiana* (Balsamo) Villemin. Careful management of this efficient predator will be necessary for continued success.

Extremely hot dry weather (over 40°C) also reduces beetle numbers. This observation is consistent with the life history studies (Table 1).

Batrachedra arenosella was a commonly occurring predator more often on heavily infested trees. Other predators (e.g. *Hemisarcoptes* sp. associated with *Chilocorus* spp.) and their possible utilization require further study (Gerson et al., 1990). In coastal areas, fungal pathogens of the scale are also probably important during wet weather. It may be that *U. citri* infestations in coastal orchards never reach the extreme levels possible in subcoastal orchards because of the competing presence of lichen and moss.

A more effective parasitoid of adult female scales on the trunk and main limbs would be a valuable complement to natural enemies of *U. citri*. *Encarsia inquirenda* appears to be the most prominent parasitoid in southern Guangdong and attempts should be renewed for its introduction.

ACKNOWLEDGMENTS

The orchard studies were done at Golden Mile Holdings, Beerwah, in Mr. A. Voss's orchard (Jovalan Farms) at Eidsvold and in Mr. B. Kugel and Sons orchard at Mundubbera. Colonies of *A. lingnanensis* were supplied by Dr. R.F. Brooks, University of Florida (HK1) and by Dr. M. Tanaka, Japanese Ministry of Agriculture and Forestry (HKJ). Mr. Soontorn Pipithsangchan of Prince of Songkhla University, Thailand, provided valuable assistance in collecting the Thai strain.

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