SEASONAL PHENOLOGY OF AUSTRALIAN CITRUS WHITEFLY (*ORCHAMOPLATUS CITRI*) IN NEW ZEALAND

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ABSTRACT

Australian citrus whitefly (ACWF) was first detected in Auckland in 2000. It has since spread to Kerikeri, Gisborne and Bay of Plenty, where it causes sooty mould problems and possibly reduction in fruit colour and tree health issues. The seasonal phenology of ACWF life stages and presence of natural enemies were assessed in citrus orchards in Kerikeri, Auckland and Gisborne. ACWF overwintered as a fourth instar/pupal stage. In Kerikeri and Auckland, the main adult emergence period was mid-October to January, with distinct periods when each immature life stage was present. In March, a small percentage of the fourth instar/pupal population emerged as adults, while the remainder overwintered before emerging the following spring. Clear and distinct periods when eggs, crawlers and nymphal stages were present were not seen in Gisborne. No parasitoids emerged from sampled ACWF and none of the predators collected in this survey appeared have any significant impact on the high ACWF populations observed.

Keywords: *Orchamoplatus citri*, Australian citrus whitefly, phenology, seasonal abundance, natural enemies.

INTRODUCTION

Australian citrus whitefly (ACWF), *Orchamoplatus citri* (Takahashi), (Hemiptera: Aleyrodidae), was first detected in Auckland, New Zealand, in October 2000. It has since spread to the major citrus growing regions of Kerikeri, Gisborne and Bay of Plenty, and south to Hawke's Bay. High populations lead to contamination of fruit and leaves by sooty mould (Pyle et al. 2005). In its native Australia, ACWF is a minor pest on citrus in some orchards only and rarely seen in others (Russell 1958; Carver & Reid 1996; Smith et al. 1997), where it is probably kept under control by natural enemies.

ACWF infests the underside of citrus leaves. The populations overwinter as immature stages that develop to adults in spring. Eggs are typically laid in a circle and hatch into first instar crawlers that settle, lose their legs and develop through three settled nymphal stages. The fourth instar nymph is sometimes called the pupal stage. Young fourth instars still feed and have a flat profile. As they age, they stop feeding and their profile becomes slightly raised, while eyespots are visible just before adult emergence. After emergence, adults move to young leaves to lay eggs.

Insecticide bioassay results indicate that crawlers, young settled nymphs and adults are the most vulnerable life stages to target with sprays (L.E. Jamieson, unpubl. data). Hence this study was initiated to determine the seasonal abundance and phenology of the different life stages of ACWF in New Zealand through field monitoring, to help determine when insecticide applications would be most effective. In addition, before embarking on a classical biological control programme, it was important to determine whether any effective natural enemies of ACWF existed in New Zealand. Therefore, natural enemies of ACWF were also sought in infested citrus orchards during this study.

METHODS

Monitoring life stages on leaves

ACWF life stages were monitored on citrus trees in six orchards. Two were in Kerikeri (mandarin), two were in Auckland (lemon in one orchard and mandarin, orange, lemon, lime, grapefruit and lemonade in the other) and two were in Gisborne (mandarin). One branch on each of 10 trees with ACWF was tagged and monitored weekly or fortnightly. The numbers of ACWF eggs, crawlers, nymphs (settled first, second and third instars), fourth instars/pupae and adults on five young and five mature leaves on each tagged branch were examined *in situ* using a hand lens and recorded, up to a maximum of 100 individuals. These numbers were then converted to abundance scores, whereby 1 = 0-9 individuals, 2 = 10-19 individuals, 3 = 20-49 individuals, 4 = 50-74 individuals, 5 = 75-99 individuals, and 6 = 100+ individuals.

If a life stage was present on only one age group of leaves (i.e. young or mature) in an orchard, then a mean abundance score was calculated based on the number of leaves of that age. However, if a life stage was present on both young and mature leaves, then the mean abundance score was calculated using the total number of leaves assessed. Calculations were conducted in Microsoft® Office Excel® 2003.

Monitoring seasonal flight activity of adults

A single yellow sticky trap (19 × 18 cm) was hung in the canopy of a tree at each orchard in October 2007 and replaced weekly or fortnightly. The trap was covered with a single layer of clear plastic wrap and sent to Plant & Food Research, Auckland, for assessment. Since it was likely that a high number of adults would be caught on a trap per week during peak flight activity, the robustness of sub-sampling each trap was determined for the first 23 traps assessed. This was done by counting the number of adult ACWF caught in a 2-cm transect across the trap. Each of these traps was divided into 9 × 2 cm transects, and the number of adult ACWF counted across each transect. These counts were then analysed using a Generalised Linear Model with a Poisson distribution to determine if there was a transect effect. Once it was established that there was no transect effect ($P > 0.05$) (i.e. the number of whiteflies were similar in each transect), all subsequent traps were sub-sampled and the number of adults was counted in a single central 2-cm transect and multiplied by nine. When the number of adults on the transect was less than 20, adults on the entire trap were counted. The calculated total number of adults was then divided by the number of days for which that particular trap had been in the orchard, to estimate the number trapped per day.

Monitoring natural enemies

ACWF-infested leaf samples ($n = 10$ young leaves and 10 old leaves per orchard) were collected without bias from different trees in each of the selected orchards, placed together in a zip-lock plastic bag and sent to Plant & Food Research, where they were stored for up to 14 days at 15°C before being examined under a microscope for parasitised ACWF. Samples of any natural enemies found were removed into 75% ethanol for identification. The sticky traps used to monitor ACWF flight activity were also examined under a microscope and samples of the different species of natural enemies removed using De-solv-it™ and placed in 75% ethanol for identification.

RESULTS

Monitoring life stages on leaves and seasonal flight activity of adults

The abundance on leaves of the different life stages of ACWF from October 2007 until March or May 2008 at each orchard are shown in Figure 1. The numbers of ACWF adults trapped at each orchard are shown in Figure 2.

In all regions ACWF overwintered in the fourth nymphal/pupal stage and these pupae were abundant on mature leaves when monitoring started in spring.

In Kerikeri and Auckland adults emerged from mid-October. Eggs were laid on soft, young leaves and were found from late October until mid January. Eggs were pale cream or green when first laid, then matured through a light brown to a dark brown-black before hatching.

FIGURE 1: Mean abundance score of each life stage of Australian citrus whitefly on leaves in (a) Orchard 1 in Kerikeri, (b) Orchard 2 in Kerikeri, (c) Orchard 3 in Auckland, (d) Orchard 4 in Auckland, (e) Orchard 5 in Gisborne and (f) Orchard 6 in Gisborne during 2007-08. Values are, in general, the mean of 10 leaves per tree and 10 trees per orchard if the particular life stage was present on mature and young leaves, or 5 leaves per tree and 10 trees per orchard if the particular life stage was present only on mature or young leaves.

Using a hand lens in the field, it was often difficult to determine whether eggs had hatched (where only the dark brown-orange egg 'shell' remained), so the abundance of unhatched eggs and the period when these were present may have been over-estimated. Crawlers emerged from late November and were present until late January. Settled first instar nymphs were present on leaves from early December when the young leaves were beginning to harden, and in January and February second and third instars were the most abundant nymphal stages respectively. The fourth instar/pupal stage was first found in early February in Kerikeri, while in Auckland they first appeared about 2 weeks later.

In Auckland a few adults, eggs and crawlers were recorded in April and May. However, these stages had not been recorded in spring, indicating they either suffered high mortality over the winter period or matured to the fourth/pupal stage over autumn and winter to contribute to the spring population of adults.

FIGURE 2: Mean number of adult Australian citrus whitefly adults caught per trap per day in Orchard 1 and 2 in Kerikeri, 3 and 4 in Auckland, and 5 and 6 in Gisborne from October 2007 to April 2008

Monitoring in Gisborne did not begin until late October, when adults were already emerging from the overwintering fourth/pupal stage. Unlike in Kerikeri and Auckland, in Gisborne all life stages were largely present throughout the period monitored. Numbers of eggs showed two distinct peaks, one in early summer and a smaller second peak in autumn. Crawlers were present from mid-November and nymphs from late December. The abundance of ACWF in the fourth/pupal stage was greatest in spring and autumn.

Populations of ACWF were much larger in Gisborne orchards than in Auckland or Kerikeri. There was a large flight of adults in spring and early summer and a smaller one in autumn (Fig. 2). The number of adult ACWF trapped in Gisborne at peak flight activity (700-3000 per trap per day) was 2-10 fold higher than in the orchards in Kerikeri (160-250 per trap per day) and Auckland (280-450 per trap per day) (Fig. 2).

Monitoring natural enemies

Parasitoids and predators collected from sticky traps and ACWF-infested leaf samples from all orchards are listed in Table 1.

There were no signs of parasitised ACWF and no parasitoids emerged from ACWF on leaf samples. Whitefly parasitoids generally belong to one of three hymenopteran families: Aphelinidae, Platygasteridae or Eulophidae. Of the 27 parasitoid species trapped, seven were in the Platygasteridae and one in the Eulophidae. Given the known host range of some of these species, and the absence of parasitised ACWF on leaf samples, none was considered likely to attack ACWF.

TABLE 1: Parasitoids and predators collected from yellow sticky traps and leaves infested with Australian citrus whitefly in citrus orchards in Northland, Auckland and Gisborne during 2007-08.

Order	Family	Subfamily/Genus/Species ¹
Hymenoptera	Bethylidae	<i>Goniozus</i> sp.
	Braconidae	<i>Aphidius</i> sp.
	Braconidae	<i>Asogaster</i> sp.
	Braconidae	Helconinae sp.
	Braconidae	Microgastrinae sp.
	Braconidae	<i>Meteorus pulchricomis</i>
	Ceraphronidae	<i>Aphanogmus</i> sp.
	Chalcidoidea	indet.
	Crabronidae	<i>Podagrirus</i> sp.
	Diapriidae	<i>Spilomicrus</i> sp.
	Diapriidae	<i>Trichopria</i> sp.
	Encyrtidae	<i>Tachinaephagus zealandicus</i>
	Encyrtidae	<i>Cryptanusia aureiscutellum</i>
	Encyrtidae	indet.
	Eulophidae	indet.
	Figitidae	<i>Anacharis zealandica</i>
	Figitidae	Eucoilinae sp.
	Figitidae	? <i>Ganaspis</i> sp.
	Mymaridae	? <i>Gonatocerus</i> sp.
	Platygastridae	<i>Aphanomerus pusillus</i>
	Platygastridae	? <i>Duta</i> sp.
	Platygastridae	<i>Gryon</i> sp.
	Platygastridae	<i>Idris</i> sp.
	Platygastridae	<i>Odontacolus</i> sp.
	Platygastridae	Playgastrinae sp.
	Platygastridae	<i>Telenomus</i> sp.
	Pteromalidae	indet.
	Signiphoridae	<i>Signiphora</i> sp.
Coleoptera	Coccinellidae	<i>Adalia bipunctata</i>
	Coccinellidae	? <i>Diomus subclarus</i>
	Coccinellidae	<i>Halmus chalybeus</i>
	Coccinellidae	<i>Rhyzobius fagus</i>
	Coccinellidae	? <i>Rhyzobius forestieri</i>
	Coccinellidae	<i>Scymnodes lividigaster</i>
	Coccinellidae	<i>Stethorus</i> sp.
	Coccinellidae	indet.
	Staphylinidae	Aleocharinae sp.
Neuroptera	Staphylinidae	<i>Anotylus brunneipennis</i>
	Staphylinidae	? <i>Carpelimus</i> sp.
	Staphylinidae	
Neuroptera	Hemerobiidae	<i>Micromus tasmaniae</i>
Acari	Phytoseiidae	<i>Amblysieus largoensis</i>
	Stigmaeidae	<i>Zetzella gonzalei</i>
	Cunaxidae	<i>Neoscirula</i> sp.

¹?=specimens that were either damaged or otherwise difficult to see diagnostic characters; and/or the taxonomy of the group is inadequately known so the identity is uncertain.

Eight species of ladybird (Coleoptera: Coccinellidae) were trapped. No ladybird larvae or eggs were found on sampled leaves, and only adult *Halmus chalybeus* were seen feeding on ACWF, suggesting that ladybirds have little impact on ACWF populations. Larvae of the lacewing *Micromus tasmaniae* (Neuroptera: Hemerobiidae) were also observed feeding on ACWF, and various species of predatory mites were associated with ACWF. Three species of Staphylinidae (Coleoptera) were trapped, but none was seen feeding on ACWF.

DISCUSSION

In Kerikeri and Auckland, there was one complete generation of ACWF per year and a partial second generation. In these regions there was a clear 2- to 3-month period when eggs, crawlers and nymph stages were each present. This study has shown that ACWF overwinters in the fourth instar/pupal stage, and that adults emerge from mid-October to January. In the northern regions, there was a small adult emergence in March (9.5% of spring emergence), but the majority of fourth instars/pupae from the summer generation emerged in the following spring. Eggs were usually found on young foliage a week after adults were first seen. The pattern of one complete and a partial generation was not as clear in Gisborne, where there was a higher population of ACWF. However, egg abundance and the flight of adults showed two distinct peaks, one in early summer and a smaller second peak in autumn. Eggs were only found on young soft leaves, suggesting that the seasonal phenology of ACWF at any site may be significantly influenced by the growth habits of the different citrus varieties present.

These observations have shown that development of ACWF is slower than that of other common whitefly species, such as greenhouse whitefly (*Trialeurodes vaporariorum*) and silver leaf whitefly (*Bemisia tabaci*), which take 28-39 days to develop from egg to adult at 22°C and can have 7-9 overlapping generations per year (Hodde 1999; Martin 1999; Zalom & Natwick 1987). The longer generation time of ACWF suggests that annual population growth will be intrinsically lower, so ACWF should be easier to control. In addition, finding a parasitoid that completes multiple generations for each one of ACWF is likely.

Insecticide bioassays have suggested that adults, crawlers and young nymphs are the most susceptible ACWF life stages to insecticides (L.E. Jamieson, unpublished data), while eggs and fourth instar/pupal stages are the most tolerant. Hence insecticides will be most effective when applied in December, when crawlers are most frequently the dominant life stage on young leaves.

Biological control has been successful against a range of whitefly species (Liotta et al. 2003; Goolsby et al. 2004; van Lenteren et al. 1996; van den Berg et al. 2000). In New Zealand, ash whitefly (*Siphoninus phillyreae*) was first found in 1995. *Encarsia inaron*, an effective natural enemy, was also collected soon afterwards, having probably arrived at the same time as its host. As a result, damaging populations of ash whitefly are now rarely seen (Charles 1998). To date no effective natural enemies of ACWF have been found in New Zealand. The low numbers of ACWF in Australia are attributed to the presence of natural enemies, although these are largely unknown. However, the parasitoid *Cales orchmoplati* (Hymenoptera: Aphelinidae) has been described from ACWF in Australia (Viggiani & Carver 1988), and E.W. Valentine introduced two species of *Encarsia*, presumably ex *O. citri*, from Australia (Nambour, Queensland) (R.L. Hill, Richard Hill and Associates, pers. comm.) to the Cook Islands in 1978 to control *O. mammaeferus* (Walker & Deitz 1979). The outcome of the Cook Island introduction has not been documented, but anecdotal evidence suggests that whitefly populations declined and it ceased to be a significant pest of citrus after that time (R. A. Fullerton, Plant & Food Research, pers. comm.).

Future research will focus on identifying and studying effective natural enemies of ACWF in Australia for potential importation into New Zealand.

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