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Emergence patterns of adult citrus gall wasp, *Bruchophagus fellis* (Hymenoptera: Eurytomidae), and its key parasitoids in southern Australia

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ABSTRACT

Emergence of adult citrus gall wasp (CGW) *Bruchophagus fellis* (Girault) (Hymenoptera: Eurytomidae) in citrus orchards in far western New South Wales, Australia, was monitored with sticky traps for three seasons (2010 to 2012 inclusive). Emergence started from early October to early November, peaked from late October to mid-November, and was mostly finished by mid–late November. Emergence timing was mainly influenced by year and site, with the largest differences observed between years. Most emergence (90%) took place during an average period of only 19 days each season (range of 11–28 days across all trap types, sites and seasons). The role of temperature in emergence timing was investigated using a degree-day (DD) model. DD accumulated since 1 April using a lower threshold temperature of 15°C and an upper threshold temperature of 35°C or 40°C gave the best predictions of median emergence dates in the three years. The required DDs to achieve 5, 50, and 95% emergence were 336, 403 and 447 DD, respectively. The maximum difference between predicted and observed median dates for 2010–2012 was only four days. CGW adult emergence in future years can be predicted using these DD parameters and a combination of observed and average historical temperature data for the target site. Effective prediction of emergence peaks will allow the timing of pesticide applications to be optimised whilst providing protection for establishing parasitoids which emerge from the galls 2–3 weeks after citrus gall wasp.

Introduction

Citrus gall wasp (CGW), *Bruchophagus fellis* (Girault) (Hymenoptera: Eurytomidae), is an endemic pest of citrus in Australia (Smith et al., 1997). The wasps emerge in spring each year and females lay their eggs inside current-year spring shoots. After hatching, the larvae burrow into the soft bark tissue and feed there until pupation. As the season progresses, the feeding areas gradually swell to form the characteristic galls each housing multiple larvae, and ultimately, pupae. Heavily infested trees can be covered with galls, resulting in very little leaf or fruit production and severe dieback.

The first record of what was almost certainly CGW attacking cultivated citrus was made by McKeown (1898) in the Richmond River area of northern New South Wales (NSW). After CGW was formally described by A. A. Girault in 1928, extensive studies on the phenology, development, and parasitoids of CGW were made by Noble (1933, 1935, 1936, 1938). During this period CGW was confined to south-east Queensland and north-east NSW (Noble, 1936), however by 1950 an isolated population was well established in suburban Sydney. Survey work conducted in 1963 showed that CGW had also expanded its contiguous northern distribution as far south as Newcastle (Hely, 1964). No parasitoids were associated with the Sydney CGW population, and deliberate releases of the principal CGW parasitoid, *Megastigmus brevivalvus* (Torymidae), were made in the area in 1957 and 1958. Monitoring in 1965 demonstrated successful parasitoid establishment and spread within the Sydney region (Gibson and Gellatley, 1968). In 1982 CGW was recorded from domestic gardens in north-western NSW and at Gosford on the Central Coast (Hely et al., 1982).

Until recently, CGW was not known from the three major orange (*Citrus* x *aurantium*) production regions in southern Australia, the Riverina, Sunraysia, and Riverland (Smith et al., 1997). In the late 1990s CGW infestations were first reported in commercial orchards in Sunraysia (Cannard, 2007). The infested area in this region quickly expanded to hundreds of hectares. In 2008, CGW infestation was found in backyard citrus trees in Griffith in the Riverina (Hardy and Creek, 2009) and in 2012 CGW was also found in commercial citrus orchards in Renmark and Loxton in the Riverland (K. Thiel, personal communication, September 2012). In 2013, galls similar to those caused by CGW were found on the outskirts of Perth in Western Australia (A. Szito, personal communication, May 2013).

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Where parasitoid populations are high over 90% of CGW larvae can be parasitized (Smith et al., 1997). The parasitoids have recently established in the new incursion areas in the south after repeated releases, however, the populations are not yet high enough to effectively control CGW (Flett, 2011). Methidathion is currently the only pesticide registered for CGW control. This chemical has broad-spectrum activity and is not compatible with citrus IPM.

Two stages of CGW are vulnerable to pesticides with contact or low-level systemic action, the adult wasps and the newly hatched larvae. The adults are the only exposed stage in the CGW lifecycle and are only present for a short period each year. The rationale for targeting newly hatched larvae is that methidathion absorption by citrus shoots is greatly reduced after the bark has hardened (Papacek and Smith, 1989). To effectively control adult wasps and newly hatched larvae, it is essential that chemical applications are precisely timed to coincide with the peak abundance of the two vulnerable life stages.

Noble (1933, 1936) provided the only published descriptions of CGW phenology including egg, larval, and pupal durations and timing of adult emergence. Most of his estimates were based on uncontrolled experiments. In this paper we report statistical distributions of CGW adult emergence in a citrus orchard as a function of degree-days based on three years of trapping data. These distributions are used to develop a forecast model to predict the timing of adult wasp emergence.

Materials and methods

Data collection

CGW adult emergence was monitored with sticky traps from 2010 to 2012 on citrus farms near Dareton in far west NSW. Most data were collected from a farm in the Coomealla Irrigation District (S34°05.369′, E142°07.230′), where CGW infestation in the region was first noted. There field emergence of adult wasps was monitored annually from 2010 to 2012 in a block of 'Autumn Gold' orange trees (Block-1, 273 × 109 m). In 2012, CGW adult emergence was also monitored at two other sites in the region, an abandoned block of lemon (*Citrus* x *limon*) trees (Block-2, 163 × 180 m) within 1 km of Block-1 and a block of 'Valencia' orange trees on a separate farm in the region about 2.5 km from Block-1 (Block-3, 207 × 217 m) (S34°04.392′, E142°07.943′). Monitoring was conducted either weekly or twice weekly starting well before first adult emergence (late September to early October) and finishing after wasp emergence had concluded (mid-December–early January).

Three types of sticky traps were used in the study: cup traps, rolled yellow sticky traps (RYST), and flat yellow sticky traps (FYST). Cup traps were made from disposable clear plastic cups (480 mL capacity, 85 mm diameter at rim). The interior cup surface was coated with a thin layer of Tangle-Trap® (The Tanglefoot Company, Grand Rapids, MI, USA) to capture emerging wasps. The traps were placed around the target galls through a 1-cm hole in the centre of the cup base and an L-shaped slit linking the cup opening to this hole. Two twist-and-tie wires attached to the opposite sides of the rim of the cup were tied around the gall-bearing stem to prevent the galls from touching the sticky surface (Fig. 1).

Double-sided yellow stick traps (75 × 110 mm, Bugs for Bugs, Mundubbera, QLD, Australia) were used either unmodified (FYST) or cut in half to provide a 75 × 55 mm section which was then rolled to form a 75 mm long tube (RYST). RYST were wrapped around galls and held in place with wire twisted around the twigs. Cup traps and RYST were each placed around randomly selected current-year galls with no exit holes. FYST were hung on twigs in the lower canopy where galls were relatively more abundant.

In 2010, 50 cup traps were placed on 25 trees and 10 FYST and 10 RYST were placed in pairs in 10 trees in Block-1. The traps were replaced weekly. In 2011, 30 cup traps were placed in 15 trees and 10 FYST in 10 trees in Block-1. The traps were replaced twice weekly. In 2012, 10 cup traps and 10 FYST were placed in pairs in 10 trees in each of Block-1, Block-2, and Block-3. These traps were also replaced twice weekly.

Fig. 1. Design of a CGW cup trap.

Traps removed from the trees were wrapped individually in plastic film and taken to the laboratory, where they were checked under a stereo microscope and the numbers of adult CGW were recorded. The number of parasitic wasps captured was also noted.

Temperature and humidity during the study period were monitored hourly in Block-1 with dual-channel data-loggers (Gemini Data Loggers, West Sussex, UK). Daily maximum and minimum temperature data at Mildura airport were obtained from the Australian Bureau of Meteorology web site (http://www.bom.gov.au). Mildura airport is 15–20 km away from the monitoring sites. Voucher specimens of CGW and the parasitic wasps have been lodged at the Agricultural Scientific Collection Unit, NSW Department of Primary Industries, Orange, NSW, Australia.

Data analysis

For each season, monitoring block, and trap type, captured wasps were summed for each trapping date. The totals were then added sequentially by trapping date to give the cumulative numbers of wasps caught by each date since monitoring started. Assuming trapping was by passive interception and the probability of a wasp being trapped was not influenced by the number of wasps already caught in the trap, the cumulative numbers of wasps caught by an inspection date would be proportional to the cumulative numbers of wasps emerged. The cumulative proportion of wasps emerged by a given trapping date can be estimated by the proportion of wasps caught by that date over the total number of wasps caught during the entire emergence period.

To predict the timing when a given proportion of the wasps have emerged, the accumulated proportions were fitted to the following Weibull distribution function (Weibull, 1961):

$$p(t) = 1 - \exp\left(-(t/\lambda)^k\right). \quad (1)$$

Where $p(t)$ is the proportion of wasps emerged by time t, and λ and k are parameters to be estimated. The time unit t was expressed either as days after 1st of September (DAS) in the corresponding season or degree-days (DDs) accumulated since a given date in the season. The former unit is independent of temperature and suited only for describing the emergence process at specific sites in individual seasons. The latter unit is temperature-dependant and suitable for describing emergence processes across sites and seasons for predictive purposes.

Parameters λ and k in Eq. (1) were estimated using the 'nlsLM' function from the package 'minpack.lm' in R (R Development Core Team,