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Macadamia Felted Coccid *Eriococcus ironsidei* (Hemiptera: Eriococidae) Description, Monitoring, and Control

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Introduction

Macadamia felted coccid (MFC), *Eriococcus ironsidei* (Williams) (Hemiptera: Eriococcidae), was originally reported on macadamia trees (*Macadamia integrifolia*, Proteaceae) in Australia by Ironside (1970). MFC infest macadamia trees and feed by inserting their threadlike stylet into the plant tissues. Damage caused by MFC includes distorted leaves, new shoots, possible abortion of immature nuts, yellow spots on leaves, and bleeding of branches. Heavy infestations result in dieback of branches and reduced yields. MFC was first detected in Hawai'i in the South Kona district on the island of Hawai'i in 2005 (Conant et al. 2005, Wright and Conant 2009). The infestation initially appeared to be restricted to South Kona, but by 2009, MFC spread to the east and northern parts of Hawai'i Island, resulting in severe infestations in many locations (Wright and Conant 2009). Current management options include applications of insecticides such as insect growth regulators and horticultural oils.

Life Cycle and General Biology

The adult females can be observed anywhere above ground on the macadamia tree, but they generally prefer to populate the lower branches and trunk of the tree. On leaves, females typically aggregate near mid-veins; in a study by Zarders and Wright (2016), males comprised

Fig. 1. Images of the different stages of *E. ironsidei* (Macadamia felted coccid): A. eggs, B. crawlers, C. male adult, D. female adult.

71% of patches of MFC on leaves, whereas 80% of the scales on branches were found to be female.

MFC eggs are elongate, 0.1 mm in length, laid under the female felted sac where they develop, and hatch after 2–4 days. The almost microscopically small crawlers have red eyes and translucent elongate bodies that gradually become orange. Red-pigmented spots can be observed on the abdomen as they develop. The legs are visible and functional as crawlers leave the ovisac. Crawlers settle on the host plant using their thread-like stylet to penetrate the plant epidermis to feed on plant fluids. The body is very fragile and measures 0.2–0.8 mm in length and 0.1–0.4 mm in width. Generally, when crawlers reach the length of 0.4 mm, they have developed a felted sac covering their body (Fig. 1) (Zarders and Wright 2016).

Female MFC have five developmental stages (egg, three juvenile instars, and adult). Their juvenile stage is completed 29–36 days after hatching. "Instars" refers to the mobile larval stage of the insects. The final instar settles, and the adult female becomes sedentary, creating a felted sac that covers her body, within which eggs are laid and hatch until the female dies. The female lifespan can be more than 50 days. The adult female body is orange, rounded, wingless, very fragile, and concealed by the white or yellowish felted sac. The eyes are dark red and minute. Short legs are visible on the body from a ventral viewpoint, but female MFC adults are sessile. They produce 18 to over 97 eggs each. As the female lays eggs, the body constricts, causing the length and width of the body to vary, but the felted sac remains approximately 1 mm long throughout her life (Fig. 1) (Zarders and Wright 2016).

Male MFC have six morphological stages (egg, four juvenile instars, and adult). Male juvenile stages develop over 13–19 days, emerging from an elongate pale white felted sac that usually measures 0.7 mm, after which the insect becomes a mature adult. The males fly to seek sexually mature females and die soon after mating (Fig. 1) (Zarders and Wright 2016).

Macadamia Felted Coccid Monitoring

Understanding the spatial distribution of an insect pest is essential for the development of effective sampling procedures, to produce data that can be used for pest-management decisions. We have collected substantial data that show statistically that MFC are highly aggregated within macadamia nut orchards (Fig. 2) (Gutierrez et al., in prep). These data are used to develop an optimized sampling procedure, which we will describe in a separate publication.

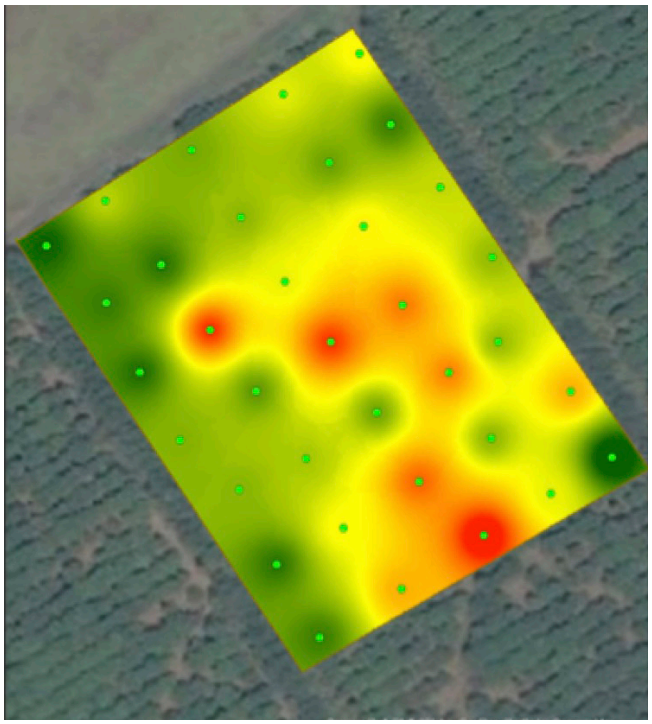

Fig. 2. Example of aggregated dispersion of MFC within an orchard. Red spots show higher numbers of MFC; green dots are individual trees.

Fig. 3. Two-sided tape wrapped around a branch of macadamia tree to monitor MFC crawler abundance.

Monitoring Methods

MFC can be monitored when they are in crawler (nymphal) and adult stages. Crawler density can be assessed by using two-sided tape wrapped around a lower branch (approximately 1.5–2 m above ground) and an upper branch (about 3–4 m above ground). The area where the tape will be wrapped should be sanded to smooth the bark surface so that crawlers can easily walk onto the tape and be trapped (Fig. 3). Tapes should be retrieved after one week to count the number of crawlers, using a microscope or hand lens. Crawler density is evaluated as the number of individuals per 6.5 cm^2 or one square inch on the tape. Adult density can be monitored by counting individuals directly from the tree. A one-inch-square section of a branch should be marked and adult individuals counted within the square (Fig. 4).

Fig. 4. Macadamia tree branch marked to monitor MFC adult abundance.

Distribution of MFC Throughout the Year

Monitoring MFC from July 2014 to December 2015 showed that MFC populations are more abundant during the drier months of the year. This trend in peak population during drier months was consistent across locations during the monitoring period and was particularly evident in Honomalino, where it is much drier than in Pahala and Honoka‘a. Wet weather conditions reduce MFC populations, as illustrated by the drastic drop in crawler population in Honoka‘a (Fig. 5) during the rainy season (summer months). Throughout the year, multiple generations of MFC were observed, a circumstance that needs to be considered when planning control strategies. It is important to monitor MFC populations throughout the year, especially at the beginning of the drier months, since MFC populations tend to double in drier seasons.

Natural Enemies of MFC

At the monitored sites, several natural enemies associated with MFC were observed: predatory beetles, including *Halmus chalybeus*, *Rhyzobeus fosteri*, *Curinus coeruleus*, *Sticholotis ruficeps*, and *Scymnodes lividigaster* (Fig. 6), as well as a hymenopterous parasitoid, *Encarsia lounsburyi* (Fig. 7). DNA gut-content analysis determined that the beetles mentioned above feed on MFC; thus these beetles may help to reduce the abundance of MFC in macadamia nut orchards. Figures 8 and 9 show evidence of predation on and parasitization of adult MFC.

The relative abundance of natural enemies differs among sites. At the Pahala site there were ten times more predators recorded than at the Honomalino and Honoka‘a sites (Fig. 10), while the parasitoid, *E. lounsburyi*, was more abundant at the Honoka‘a site

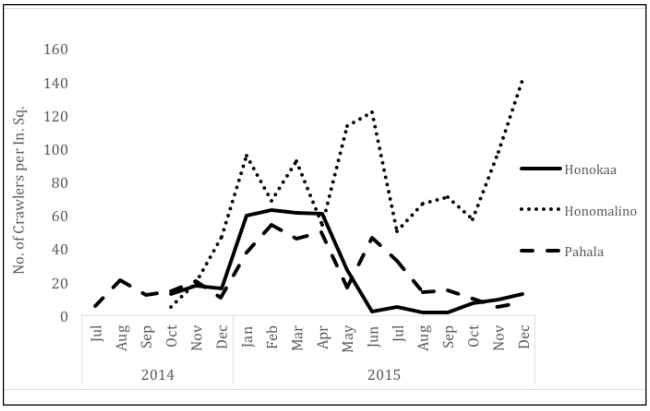

Fig. 5. Abundance of MFC crawlers from July 2014 to December 2015 at 3 locations on Hawai‘i Island.

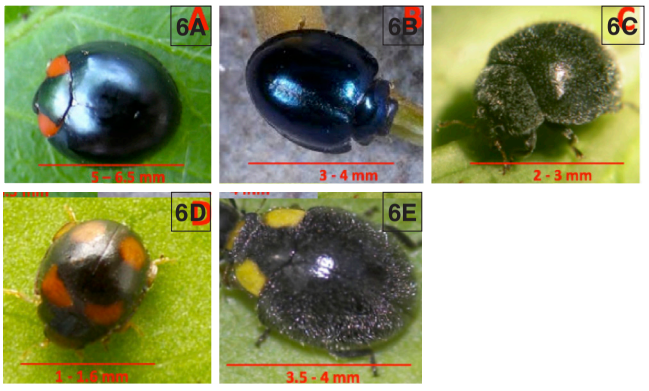

Fig. 6. Predatory insects of MFC present in macadamia nut orchards in Hawai‘i. A) *C. coeruleus*, B) *H. chalybeus*, C) *R. forestieri*, D) *S. ruficeps*, and E) *S. lividigaster*.

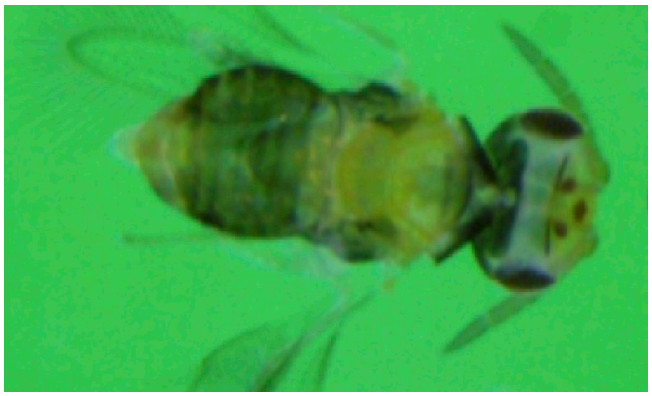

Fig. 7. An adult parasitoid of MFC, *Encarsia lounsburyi*, measuring 0.02 mm long. *E. lounsbury* lay their eggs in the MFC nymphs and adults.

Fig. 8. Evidence of predation on an MFC adult.

Fig. 9. A neat round hole indicates that this adult MFC has been parasitized.

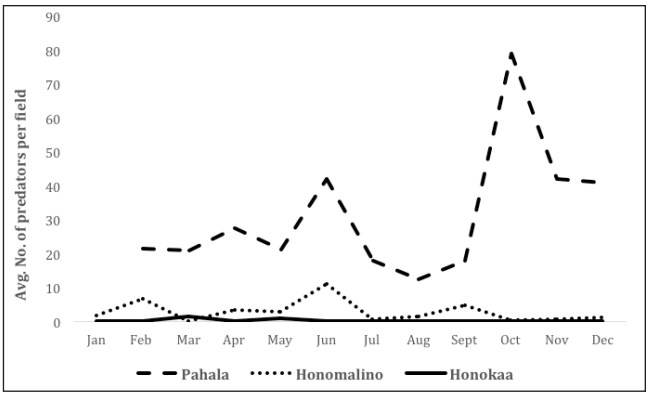

Fig. 10. Abundance of MFC predators in macadamia orchards at 3 locations of Hawai'i Island during 2015.

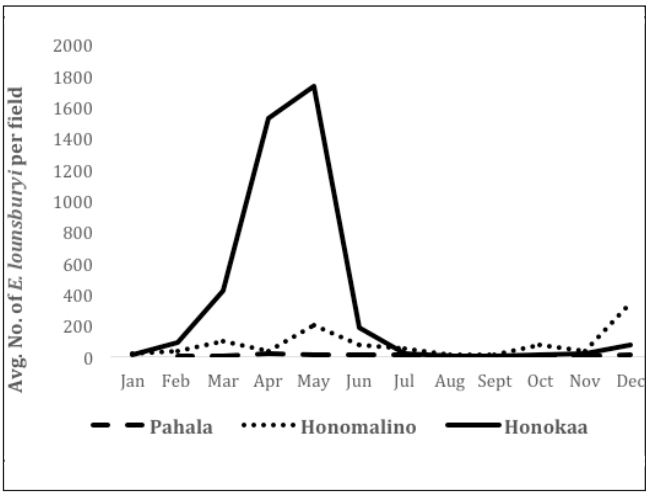

Fig. 11. Abundance of the parasitoid *Encarsia lounsbury* in macadamia orchards at 3 locations on Hawai'i Island during 2015.

compared to the Honomalino and the Pahala sites, particularly during the spring season (Fig. 11).

Control of MFC With Insecticides

Insecticides that are generally used to control MFC are insect growth regulators (IGRs) and horticultural oils. Recently tested IGRs are Esteem® 35 WP (Pyriproxyfen, Valent U.S.A. Corporation, Walnut Greek, CA) and Centau® (Buprofezin, Nichino America Inc., Wilmington, DE) (Fig. 12). Esteem® is labeled for use on macadamia nuts and is effective against MFC. This product, however, has significant negative impacts on ladybeetles, which are

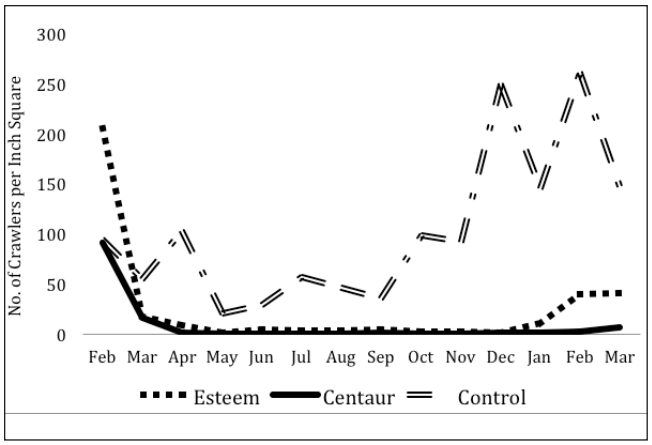

Fig. 12. Numbers of MFC crawlers on trees treated with Esteem® 35 WP and Centaur® decrease one month after pesticide application and remained low for up to 9 months, while control numbers rise significantly.

beneficial predators of scale insects. Centaur® is labeled for nuts in general, is effective against MFC, and does not negatively affect beneficial insects. Both these IGR products are only effective at controlling the crawler stage of MFC. They do not effectively control adult MFC. Insecticide trials showed 95% control of MFC crawlers with Esteem® and 99% control with Centaur®. Also, the effect of Centaur® can last longer (about 18 months) than Esteem® (up to 12 months); however, Centaur® does have a 60-day pre-harvest interval, which may limit application options.

The horticultural oils Saf-T-Side® and TriTek® are registered as organic products that do not affect beneficial insects such as ladybeetles; however, these products only control adult MFC (Wright 2009). Saf-T-Side® trials showed that good control of adult MFC can be achieved if good spray coverage is achieved; however, crawlers are unaffected by oil application, so a second application of oil must to be made 15–20 days after the first application to suppress the crawlers that survive to adulthood.

Conclusions

Multiple generations of MFC occur throughout the year, which should be considered when planning control strategies. It is important to frequently monitor MFC populations in dry areas and as soon as the dry season starts, since this is the environment that favors severe outbreaks of MFC. Insecticide treatments with insect growth regulator compounds are appropriate when populations of MFC are high (approximately > 50 crawlers per in^2 per tree); otherwise, horticultural oils combined with natural enemies can effectively control low MFC infestations.

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