BIOLOGICAL CONTROL AGENTS OF THE CYCAD AULACASPIS SCALE, AULACASPIS YASUMATSUI

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Abstract. Biological control is a key element in any management program to control the cycad aulacaspis scale, Aulacaspis yasumatsui Takagi. An overview of the natural enemies known to attack the scale is presented. Sixteen species of predatory lady beetles (Coccinellidae) have been collected on scale-infested cycads in south Florida. Chilocusus cacti (L.), Cryptolaemus montouzieri Mulsant and Exochomus childreni childreni Mulsant are frequently encountered, but do not suppress scale populations. Rhyzobius lophan-thae (Blaiddell) is a voracious predator that reportedly provides good control of cycad aulacaspis scale in Hawaii, but has a sparse distribution on cycads in Florida. The minute predatory beetle Cybocaphalhus nipponicus Endrody-Younga is abundant and widespread throughout the USA and contributes to limited scale mortality. The parasitic wasp Coccoebius fulvus (Compere and Anneke) was introduced from Thailand into Florida in 1988, but has not been effective in controlling the pest. Overall parasitism in south Florida varies from 10 to 40%. Arrhenophagus chiosaspis Aurivillius and Aprostocetus purpureus (Cameron) parasitize cycad aulacaspis scale throughout Southeast Asia and are currently under study as potential biological control agents in Florida. Four commercially available entomopathogenic nematodes were tested in the laboratory and all were observed infecting and killing female scales. No pathogens are known to cause disease in the cycad aulacaspis scale.

Cycads, commonly called “sago palms”, are highly desired by landscapers and homeowners because they are long-lived, require low maintenance, and are resistant to most pests. In 1995, a scale insect, Aulacaspis yasumatsui Takagi, also referred to as the cycad aulacaspis scale (CAS), was discovered infesting cycads in the collection of the Montgomery Botanical Center in Coral Gables, Florida. Infestations of the scale were found to be particularly severe on Cycas spp. and Stange-ria eriopus (Kunze) Baillon (Howard et al. 1999). This pest produces dense populations on the leaves, fruits, and trunk, resulting in premature death of leaves which can reduce plant longevity. Cycas revoluta Thunberg (the king sago), the most popular of ornamental cycads, is particularly susceptible to the scale; many plants throughout Florida and the Caribbean have died as a result of this pest.

Hawaii was found to be infested with the scale when CAS was detected on Oahu in 1998 (Hara et al., undated). On Guam, CAS was detected in 2003 on an individual of C. revul-ta, but within 2 years it spread to most of the island (Terry and Marler 2005). It now has invaded native forests where it infests Cycas micronesica K.D. Hill, an indigenous species unique to Micronesia. In some areas the mortality rate of these 100-year-old trees is 100%. The entire population of 1.5 million C. micronesica trees is now threatened to succumb to CAS before suitable biological control agents are found and released. Moreover, nurseries on Guam export plants to other Micronesian islands that have C. micronesica, so it is likely that the scale will spread throughout Micronesia.

Classical biological control of CAS began in 1998 when a parasitic wasp, Coccoebius fulvus (Compere and Anneke), and a predatory beetle, Cybocaphalhus nipponicus Endrody-Younga, were imported from Thailand and released in Florida (Hodgges et al., 2003). Since then, no additional natural enemies have been released. This paper provides an overview of the natural enemies of CAS that have become known in recent years, some of which are currently being investigated as potential biological control agents in Florida and other areas where CAS is a problem.

Predators

Sixteen species of ladybird beetles (Table 1) have been collected from cycads infested with CAS in south Florida during the period 2003-2005. Six species were rarely encountered, i.e., less than 6 individuals were observed during the 3-year period, and another 4 species were seen on a few occasions throughout the year but never more than 5 individuals on a plant at a time. Three frequently encountered species, Chilocusus cacti (Linnaeus), Cryptolaemus montouzieri Mulsant, and Exochomus childreni childreni Mulsant, were found in nearly all months of the year and often with up to 20 individuals on a plant. Five species are non-native and were introduced into North America during biological control projects targeted against other pests.

Rhyzobius lophan-thae (Blaiddell), a native of Australia, is considered one of the most economically important natural enemies of armored scale insects (Rosen, 1990; Stathas, 2001; Yus, 1973). It was released in California in 1892 and subsequently has spread throughout the southern United States, including Florida (Gordon, 1985). Frank and McCoy (1994) indicated that importations of R. lophan-thae imported into Florida (year(s) not reported) were targeted against the ole-ander scale, Aspidiotus nerii Bouché, and other “scale insects”. It was introduced into Hawaii in 1894 for control of other armored scales but reportedly provides good control of CAS (Hara et al., undated). Recently, this same beetle was released in Guam. In the laboratory I have observed this voracious predator destroying nearly entire CAS populations on heavily infested plants. In Florida, it has only been seen on CAS-infested cycads in the downtown Tampa area and on the campus of Florida State University in Tallahassee. It is odd that, given the wide and abundant distribution of CAS throughout...
Table 1. Ladybird beetles (Coccinellidae) collected from cycads infested with Aulacaspis yasumatsui in south Florida. Asterisk (*) indicates non-native species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Relative abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chilocorus cacti (Linnaeus)</td>
<td>Frequently encountered in low numbers</td>
</tr>
<tr>
<td>Chilocorus circumdatus (Schönherr)</td>
<td>Rare</td>
</tr>
<tr>
<td>Chilocorus stigma (Say)</td>
<td>Rare</td>
</tr>
<tr>
<td>Cryptolaemus montrouzieri Mulsant*</td>
<td>Frequently encountered in moderate numbers</td>
</tr>
<tr>
<td>Curinus coerules Mulsant*</td>
<td>Occasionally encountered in low numbers</td>
</tr>
<tr>
<td>Cycloneda sanguinea (Linnaeus)</td>
<td>Occasionaly encountered in moderate numbers</td>
</tr>
<tr>
<td>Diomus australis Gordon</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Eucharus childreni childreni Mulsant</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Harmonia axyridis (Pallas)</td>
<td>Rare</td>
</tr>
<tr>
<td>Hippodemia convergens Guérin-Meneville</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Hyperaspis ornata Mulsant</td>
<td>Rare</td>
</tr>
<tr>
<td>Microwesia coccidiva (Ashmead)</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Olla v-nigrum (Mulsant)</td>
<td>Localized, but in large numbers</td>
</tr>
<tr>
<td>Rhyzobius lophantae (Blaisdell)</td>
<td>Rare</td>
</tr>
<tr>
<td>Zilus subtropicus (Casey)</td>
<td>Infrequent</td>
</tr>
<tr>
<td>Zilus sp.</td>
<td>Infrequent</td>
</tr>
</tbody>
</table>

Female C. fulvus are also hyperparasitized by the aphelinid Aplerus elegans (Silvestri), but this mortality agent does not appear to be a significant factor limiting C. fulvus as a biological control agent. Approximately 15,000 individuals of C. fulvus were released from February-April 2002 in 14 Florida counties (Hodges et al., 2003). The wasp is now widespread throughout south Florida, but its northern range is apparently defined by its in-

Parasitoids

Female C. fulvus lay their eggs in 2nd instar and adult female CAS. The wasp develops parasitically within the host's body for approximately 15 days at 25°C. Near the completion of the wasp’s larval development, the host’s body mummifies to become a hard, transparent shell with a typical form (Fig. 1). The wasp larva pupates within the host mummy, spending about 6 days in this stage. When the adult wasp emerges from the pupa, it uses its mandibles to cut a circular hole in the host mummy, liberates its head from the mummy, cuts another circular hole through the host’s armor, and then emerges into the environment. Males develop as hyperparasites in or on the body of larval female C. fulvus, but the population of males on a plant is always very low (Cave, unpublished data).
tolerance to cold temperatures during the winter months. Rates of parasitism may reach close to 100% on individual leaflets, but overall parasitism by C. fulvus on a plant is usually between 10 and 40%, with greater parasitism occurring at higher scale densities on leaves (Cave, unpublished data).

Dr. Hui Ren, an insect taxonomist retired from the Guangdong Entomological Institute where he specialized in the study of parasitic wasps of the families Aphelinidae and Encyrtidae, has collaborated with University of Florida (UF) and Division of Plant Industry (DPI) scientists the past two years to find parasitoids with potential for release into Florida. During 2003-2005, the following 4 parasitoid species were sent to the DPI quarantine facility in Gainesville:

- Arrhenophagus chionaspis Aurivillius (Encyrtidae)
- Pteroptrix chinensis (Howard) (Aphelinidae)
- Aphytis lepidosaphes Compere (Aphelinidae)
- Thomsonisca sankarani Subba Rao (Encyrtidae)

Additionally, Dr. Ru Nguyen of DPI has observed Aprostocetus purpureus (Cameron) (Eulophidae) and Encarsia sp. (Aphelinidae) parasitizing CAS in Vietnam. All these parasitoids are general armored scale parasitoids, but the most promising is A. chionaspis because it causes high levels of parasitism of male scales in China. Current research with this insect is ongoing in the quarantine facilities in Gainesville and Ft. Pierce. Aprostocetus purpureus from Vietnam also looks interesting because it appears to cause significant mortality in that area. The taxonomy and biology of these parasitic wasps need thorough study before a release permit can be authorized.

Coccobius fulvus not only parasitizes CAS but also attacks the arrowhead scale, Unaspis yanonensis (Kuwana) (Furuhashi and Nishino, 1983), which is a pest of citrus in China and Japan. Arrowhead scale is also parasitized by the wasp Aphytis yanonensis DeBach & Rosen. Furuhashi and Nishino (1983) report that arrowhead scale is effectively controlled in Japan where C. fulvus and U. yanonensis work in tandem. There is no report of CAS being exposed to and parasitized by U. yanonensis. However, since C. fulvus attacks both CAS and arrowhead scale, it is possible that U. yanonensis will do the same, i.e. attack arrowhead scale and CAS. This needs to be tested in the laboratory.

**Entomopathogenic Nematodes**

Aulacaspis yasumatsui not only infests the leaves of cycads, but also penetrates minute sites on the trunk and roots of the plant. Scales in these microhabitats are inaccessible to parasitoids and predators. Four species of entomopathogenic nematodes have been tested in the laboratory to determine their capability to infect adult and nymphal female CAS. Sten nematema fideliae (Filipjev), Heterorhabditis indica Poinar, Karunaka and David, Heterorhabditis marelatus Liu and Berry, and Heterorhabditis bacteriophora Poinar can attack and kill 2nd instar and adult female CAS, with H. indica and H. bacteriophora causing slightly greater rate of mortality than the other two nematode species (Cave, unpublished data). Experiments need to be conducted in the field in order to determine the best nematode species and application method for controlling CAS on the trunk and roots.

**Pathogens**

No primary pathogens are known to cause disease in the cycad aulacaspis scale. The piercing-sucking mouthparts of this sessile insect do not allow ingestion of bacteria or viruses that commonly attack mobile, chewing insects. Also, the armor produced by 2nd instar nymphs and adult females serves as a formidable barrier to spores of entomopathogenic fungi such as Beauveria and Metarhizium. However, Yasnosh and Tabatdzé (1997) discovered a species of Aschersonia that attacks armored scales in Georgia, thus offering a glimmer of hope that a similar pathogen may exist for CAS.

Additional natural enemies of CAS, particularly specialist parasitic wasps, may exist in Asia and only need be discovered. Exploration to areas within the homeland of CAS, such as Hainan (China), northern Vietnam, Ryukyu Islands, Malaysia, Indonesia, and the Philippines, needs to be conducted to find all possible biological control agents. After general observation in the field, candidates must be more thoroughly studied in the quarantine laboratory before petitions for field release are prepared and submitted.

**Literature Cited**


